MIT Technology Review

Feature p. 48
Artificial Hand, Real Feeling

Business Report p. 61
Data & Decision Making

Demo p. 84
Off-the-Grid Power

MAR/APR 2014 $5.99

The Smartest Company in the World. And It's Not Google.*

*Google is number three.

Find out who ranks higher in our fifth annual tally of the **50 Smartest Companies** in the world, starting on page 26.

Introducing the K900, from Kia.

Challenge the luxury you know.™

They say that tradition is what makes a luxury sedan, but is that truly the case? Or can luxury simply be defined by the way something looks? The way it feels? The way it makes you feel? Perhaps it's the way it makes others feel about you? While some will cling to the notion that heritage is what makes a luxury sedan, the open-minded will form an opinion of their own.

2015 K900 V8 expected Spring 2014. Initially only available in select markets with limited availability. 2015 K900 V8 prototype shown with optional features. Not all features are available on all trim levels. THE MATRIX, THE MATRIX RELOADED, THE MATRIX REVOLUTIONS: ™ & © Warner Bros. Entertainment Inc. (s14)

kia.com/K900

KIA

From the Editor

GUIDO VITTI

THE 50 COMPANIES ON OUR ANNUAL LIST of the "smartest" businesses in the world (page 26) make disruptive technologies. The phrase is much abused by technologists. Mostly, it just means "new and good." Insofar as it can be used precisely, it must be employed as Clayton Christensen, the Harvard Business School professor who coined the phrase, intended: he wanted to convey the idea that certain innovations possess "attributes" that create new (initially low-end) markets and displace existing businesses.

The 50 are ranked more or less arbitrarily. Nonetheless, three companies —Illumina, Tesla, and Google—justifiably lead our list, by virtue of the disruptiveness of their technologies and the intelligence with which they built their businesses.

Illumina, the smartest of all, wowed us. The company exploits the fundamental copying mechanism of DNA in order to read the sequence of a human genome. (The process is called sequencing by synthesis: fluorescently labeled bases are added to single DNA strands from a sample and read, in massively multiplexed fashion.) Through technology it invented or acquired from Solexa, Illumina has forced an astounding increase in the pace of sequencing and an equally astounding drop in sequencing's cost (five times faster than Moore's Law). Illumina's machines are beautiful to contemplate: so slick they don't have a single button and so powerful they can generate a genome for $1,000. (By contrast, the Human Genome Project cost $3 billion; as recently as 2006, it cost $10 million to sequence a human genome.)

Illumina's technology is truly disruptive. In richer countries, everyone's genomes will be decoded. The impact will be new categories of drugs, better matching of therapeutics to the patients who will benefit most, and startling insights into what makes us human.

Elsewhere in the issue, we describe two other disruptive technologies: Google Glass (see "Glass, Darkly," by Simson Garfinkel, page 70) and Bitcoin (which is owned by no company: see "Marginally Useful," by Paul Ford, page 80). Glass, Garfinkel writes, "fundamentally transforms … human-computer interactions, making them more intimate." Ford says, "Today, there are thousands of people loyal to the ideology and opportunities that Bitcoin represents. They imagine a world where economies are less dependent on banks and governments, and they're actually using Bitcoin, often in disruptive ways."

But Illumina's technology, Glass, and Bitcoin are not only disruptive (in the sense that new markets for novel things displace older markets and things, and all the associated human habits that attached themselves to those old things). The developer and blogger Dave Winer recently wrote, "Every [successful] product is both disruptive and constructive. It disrupts someone's business, and adds new art." This must be right; new technologies would not be embraced if they were merely destructive. Successful products always offer more to customers (or to some powerful component of society) than the costs of their adoption.

Clay Shirky, a professor at New York University, likes to say, "It's not a revolution if nobody loses." With a little science-fictional speculation, one can imagine the negative consequences of genome sequencing, Glass, and Bitcoin, and one can guess who would suffer most if they were broadly adopted. (Briefly: communities with genetic defects, who could face discrimination or be edited out of existence; we who care about privacy; and anyone who has ever benefited from monetary policy.) But, equally, it's true that there are no revolutions if no one benefits. *Therefore that it may raise up, technology throws down.*

Infinite Designs, One Platform

with the only complete system design environment

NI LabVIEW is the only comprehensive development environment with the unprecedented hardware integration and wide-ranging compatibility you need to meet any measurement and control application challenge. And LabVIEW is at the heart of the graphical system design approach, which uses an open platform of productive software and reconfigurable hardware to accelerate the development of your system.

LabVIEW system design software offers unrivaled hardware integration and helps you program the way you think–graphically.

>> Accelerate your system design productivity at ni.com/labview-platform

800 453 6202

NATIONAL INSTRUMENTS

Contents

Front

You feel me?
p. 48

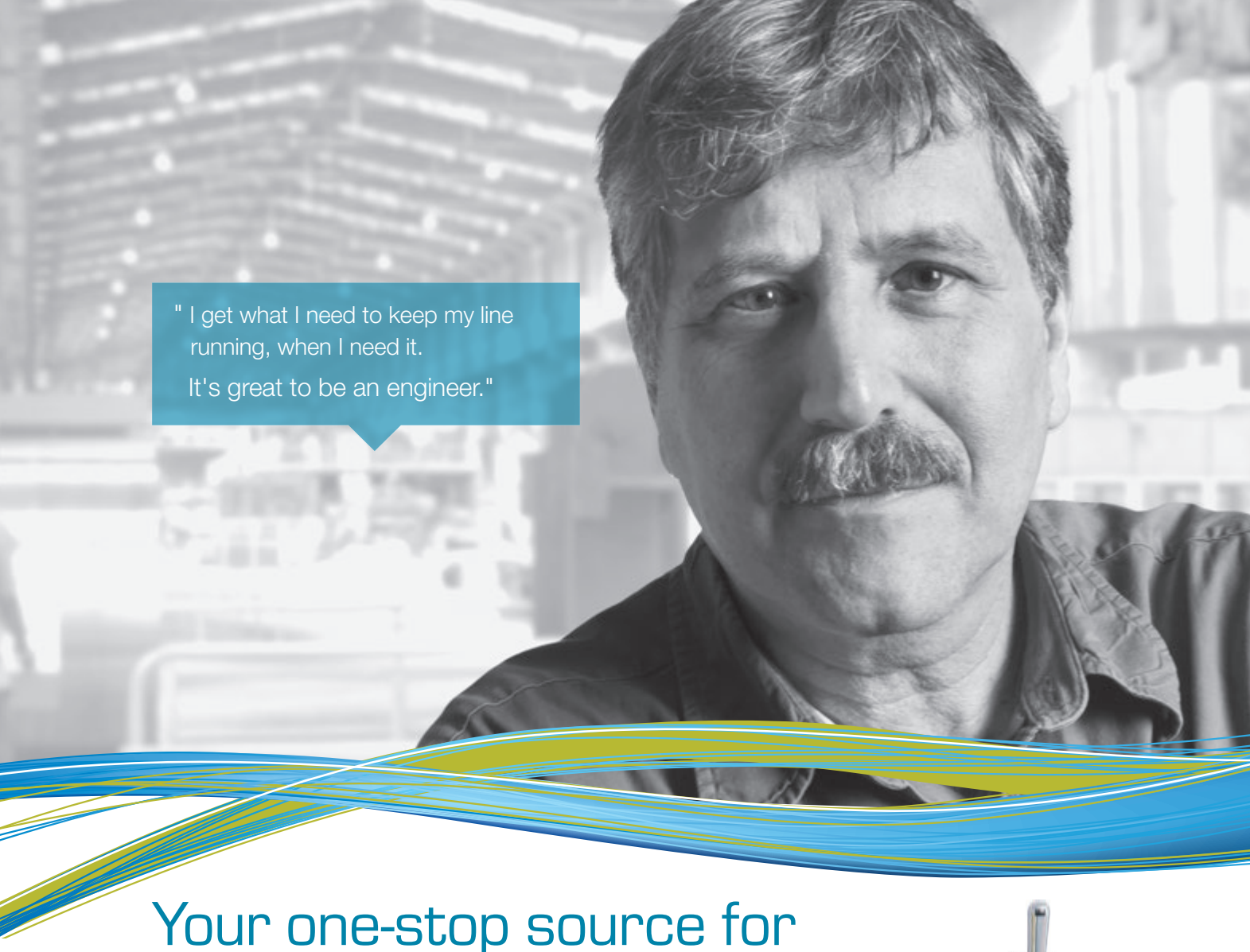
March/April 2014

Back

"Using Glass is like being naked with the machine: wires and synapses united."

Our review of Google Glass begins on p. 70

RYAN DONNELL



Your one-stop source for INDUSTRIAL ELECTRONICS

For Industrial Automation and Control, we have the products & solutions you need from the most trusted brands.

newark.com | 800.463.9275

TE connectivity

Authorized Distributor

Featured product:
Gemini Series Toggle Switch
(25R3493)

Newark™ element14™

CUSTOMER SERVICE AND SUBSCRIPTION INQUIRIES
National: 800-877-5230

International: 818-487-2088

E-mail: technologyreview@pubservice.com

Web: www.technologyreview.com/customerservice

MIT Records: 617-253-8270 (alums only)

Permissions: Jennifer Martin
jmartin@wrightsmedia.com
281-419-5725

———

Technology Review
One Main Street, 13th Floor
Cambridge, MA 02142
Tel: 617-475-8000

———

MIT Technology Review identifies the new technologies that matter—explaining how they work, deciphering their impact, and revealing how they'll change our lives. Founded at the Massachusetts Institute of Technology in 1899, we are a digitally oriented global media company that publishes serious journalism in magazines and on websites and mobile devices. We also host events around the world. Technology Review, Inc., is an independent nonprofit 501(c)(3) corporation wholly owned by MIT; the views expressed in our publications and at our events are not always shared by the Institute.

De Technologia non multum scimus. Scimus autem, quid nobis placeat.

Stop the Pirates From Parroting Your New Ideas

Since 1972 the Intellectual Property law firm of **Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.** has protected the intrinsic rights of clients' original ideas and new technologies through the application of trademarks, copyrights, patents, licensing, trade secrets & infringement protection and unfair competition litigation. Protect your next brain storm with the brain trust of an Intellectual Property law firm. Please contact **ADDM&G** today for further information. **www.addmg.com**

ADDM&G

ALLEN, DYER, DOPPELT, MILBRATH & GILCHRIST, P.A.

INTELLECTUAL PROPERTY ATTORNEYS

Listed in Intellectual Property Today as:
22ND in the nation for trademarks issued
Top 100 in the nation for patents issued

2012 2013 BEST LAW FIRMS U.S.News Best Lawyers

ALLEN, DYER, DOPPELT MILBRATH & GILCHRIST, P.A. TOP LISTED IN Best Lawyers THE WORLD'S PREMIER GUIDE

Orlando · 407·841·2330 | Jacksonville · 904·398·7000 | Melbourne · 321·622·8651
Miami · 305·374·8303 | Tampa · 813·639·4222* | Winter Springs · 407·796·5064

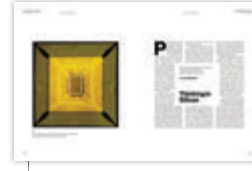
GRAY MATTER MATTERS

*Satellite Office

Feedback

Five Most Popular Stories

MIT Technology Review Volume 117, Number 1



1

GMOs

David Rotman's article makes a great point, showing that low public opinion and high risk make funding research near impossible for all but large companies. As a native Floridian, I am deeply concerned with the future of the Florida citrus industry, which is threatened by a citrus greening disease. A couple of genes from spinach could save this crop. **—wdezern**

The flaw in Rotman's article is the idea that we need GMOs to increase the food supply to keep up with population growth. If somehow we do expand the food supply through GMOs or any other gimmick, we will only beget more people. **—lap**

2

Thinking in Silicon

This is a great article because this is a paradigm-shifting line of research. Arguments about whether we are going to have a computer with human intelligence have their place, but that place is principally philosophical. The real question is simple: can it work better?

—woodstock Dan

This is impressive science. Since the drone industry is so clearly salivating over this research, I suggest that one early application would be reliably differentiating wedding processions from terrorist convoys.

—lmkory

3

Q&A: Danah Boyd

National crime statistics show that children are not in more danger from predators than they were in the 1950s or 1960s. What has changed is our awareness of crime due to the 24-hour news cycle. It's no wonder parents worry, but yes, it is safe to let your kids out of the house. Ironically, one danger that has increased slightly is your child's odds of being struck by a vehicle while crossing the street. Why? Because he or she may be distracted by the phone.

—vertical

4

The Continuous Productivity of Aaron Levie

I began using Box because I liked the site's straightforward visual presentation and felt free of the Big Brother vibe that companies like Google exude. It wasn't until I taught developmental English at a local community college that I realized the ease of collaboration offered by Box. Using Box was simple enough to introduce to technologically challenged students, who lost many excuses like "I forgot my essay," and peer collaboration was more streamlined through Box than it was through the college's online course component.

—Mrs_Moore

5

Too Much Information

The article asks, do we have the wisdom to direct our own evolution? Well, don't women do that already? They choose their sexual partner.

—Cathal Haughian

Clearly this will impact the business of artificial fertilization. Let a collection of eggs be fertilized and analyze them, then pick the ones with the most "desired" traits. Possibly offer a couple of key edits via CRISPR to eliminate inheritable mutations like BRCA and all descendants will be free of it. *Gattaca,* anyone? **—Sanescience**

E-mail letters@technologyreview.com

Write *MIT Technology Review*
One Main Street, 13th Floor
Cambridge, MA 02142

Please include your address, telephone number, and e-mail address.

Letters and comments may be edited for both clarity and length.

Are GMOs Worth the Trouble?

IN "WHY WE WILL NEED GENETICALLY Modified Foods," David Rotman argues that we'll need GMOs to deal with an increasing population and climate change. He bases his argument, in part, on the presumption that plant breeding—one alternative to GMOs—is too slow and won't adapt to climate change in a way that will increase yields enough.

Many breeders and molecular biologists would disagree. Research on many major crops over the past 20 years has shown that current widely grown crop varieties use only a small fraction of their genetic potential. The so-called "yield plateau" of the last several decades in some crops is more likely due to complacency after the green revolution than to deficiencies in breeding potential.

While breeding continues to meet important challenges like improving drought tolerance, improving nitrogen fertilizer efficiency, or increasing yield, genetic engineering has contributed little or nothing. There is now one variety of genetically modified corn, tolerant to moderate drought, which would improve overall productivity by only about 1 percent in the United States. By contrast, breeding and agronomy have improved corn drought tolerance by about 1 percent *per year* over the past three decades.

And what about nongenetic alternatives? Rotman's argument completely neglects these means to increase food security. One prominent environmental scientist, Jonathan Foley of the University of Minnesota, concluded in a recent article that "while future genetically modified crops could add other beneficial plant traits, which might help boost productivity in crucial crops, I think the best answers lie elsewhere." He pointed to alternatives, including reducing food waste, reducing our consumption of animal products, and reducing the amount of food crops used for biofuels. And using agroecology-based methods greatly improves sustainability and resilience.

It's worth noting that there's no real consensus on GMO crop safety. Although many of the crops may well be benign, some could be harmful, prompting unresolved questions about the adequacy of current regulations.

There are other substantial unresolved challenges associated with GMOs, including the high economic concentration of the seed industry, facilitated by gene patents. The main uses of the technology also seem to encourage the expansion of industrial monoculture farming, with all its problems. And most of the pipeline for genetically modified foods is more of the same—herbicide-resistant crops that will only, in the end, exacerbate pesticide use.

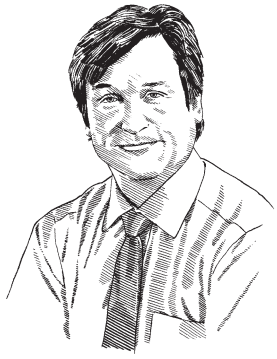
Doug Gurian-Sherman is a senior scientist in the Food and Environment Program at the Union of Concerned Scientists, a nonprofit science advocacy group.

David Rotman responds:

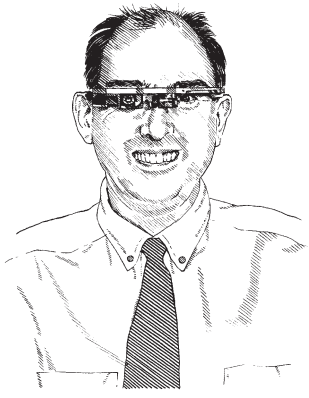
AFTER INTERVIEWING MORE THAN A dozen plant breeders, some of whom are also molecular biologists, I found none as sanguine as Gurian-Sherman about the ability of conventional breeding methods to keep up with population growth and the negative impacts of climate change. These scientists work all over the world, and they had the same message: genetic modification could be a vital tool in plant breeding.

The problem with Gurian-Sherman's argument is the sweeping dismissal of GM technology. Of course GMOs should be regulated and monitored. And of course there are other things that should be done (is anyone against reducing food waste)? But that doesn't exclude researching the potential for future versions of genetically modified crops.

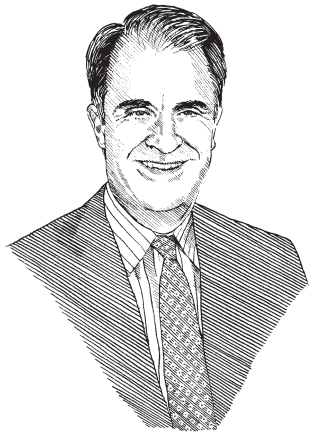
Views



Howard Jacob



Steve Mann



David Yermack

MEDICINE

Cheap Genomics

Now that genomes can be sequenced for $1,000, more patients can benefit, says Howard Jacob.

The quest for the $1,000 genome sequence began in December 2001 at the National Human Genome Research Institute's scientific retreat. That quest appears to have been completed with Illumina's January announcement of the HiSeqX Ten machine (see "Illumina," page 28). Fifteen years after the first human genome was sequenced at a cost of $2.7 billion, we are at the dawn of a new era in medicine.

Many more genomes will now be sequenced, and they will be sequenced in much more detail. Today, because examining the whole genome has been so costly, most clinical and research labs look only at the exome, the roughly 1.5 percent of the genome associated with known functions. You might say that we are only looking where we understand. The ability to sequence the whole genome affordably will now generate an abundance of data and an opportunity to understand the importance of many more genetic variants. Sequencing the entire genome typically finds hundreds of times as much variation between any two individuals as just sequencing their exomes, most of it in regions of the genome that are poorly understood.

Learning the functions of those regions will help scientists better understand diseases, drug side effects, and the mechanisms by which the genome functions. Early efforts to use whole-genome sequencing in health care have produced promising results. In our clinic at the Medical College of Wisconsin and Children's Hospital of Wisconsin, we have already used whole-genome sequencing to identify the causative variant, or mutation, in 26 percent of unexplained diseases we have taken on. The national rate of success without sequencing the genome is between 5 and 10 percent.

Being able to routinely use genome-wide sequencing in the clinic should make it possible to treat patients with an eye to their genetic predisposition toward specific diseases and their responsiveness to particular treatments. We already have evidence that this can improve success rates and reduce costs, which should make these technologies appealing to health insurers.

However, we aren't there yet. More genomic data must be gathered and shared if we are to understand it well enough to affect clinical outcomes on a large scale. We must also remember that a genome sequence is only the first step; it must be followed up with genetic counseling and evidence-based care. Ethics must also be part of the discussion, because decisions about genomic screening affect generations to come. Now that the technology needed to deliver the $1,000 genome has arrived, we must determine the best way to use this information to save lives.

Howard Jacob is director of the Human and Molecular Genetics Center at the Medical College of Wisconsin.

COMPUTING

Glass Allowed

Hostility to the use of wearable computers and cameras threatens to limit their benefits, says Steve Mann.

Many of us who use a wearable computer to augment our vision have come to rely on it as our normal way of seeing, understanding, and making sense of the world. As we get older, whether we become reliant on the technology through loss of natural function or merely grow further

ILLUSTRATIONS BY SAM KERR

Northern Ireland - the technology talent pool

Northern Ireland's knowledge economy is growing nearly three times faster than the UK average and Belfast is rapidly gaining a reputation as an innovation hotspot.

The city has been named Europe's leading destination for software development and technical support investment. It is also number one internationally for investment in financial services technologies attracting The Chicago Mercantile Exchange, Citi and NYSE Euronext. A 2013 Barclay's report revealed the number of 'high growth' companies there is soaring. Some achievement for a region with a population under 2 million.

Northern Ireland boasts a long tradition of invention and ingenuity, with Belfast Harbour once leading the way for engineering and industry. A century ago, its Queen's Island shipyards were the envy of the world.

With an $11.2 billion regeneration scheme underway - among the world's largest urban waterfront redevelopments - the Titanic Quarter is home to today's fastest growing sector, technology. At the Northern Ireland Science Park over 100 technology companies are revitalizing Belfast's reputation for forward-thinking. This hub is one of many knowledge-based clusters in the region.

Companies establishing bases there benefit from the resources of the clusters and can quickly recruit talent.

U.S. companies such as Liberty Mutual and the Allstate Corp are using Northern Ireland based teams to support global operations and customers, Citi drives trading research and development and Merchant Warehouse to create next-generation platforms and products.

Northern Ireland's two highly-regarded universities not only produce an exceptional talent pool; both are commercializing research output. These academic institutions offer research and consultancy services to business, turning intellectual property into marketable products and services. Together the universities have fostered scores of fast-growing spinout companies and helped secure venture capital investment. Testament to the strength of the start-up scene is the acquisition of local based tech companies by blue-chip firms including Intel & HP.

Across Northern Ireland, research centers of excellence and technology incubators nurture clusters in telecoms, cybersecurity, financial services, aerospace, data analytics, cloud computing, mobile, healthcare technology and nanotechnology.

Cybersecurity is a particular strength. CSIT (Centre for Secure Information Technologies), at Queen's University Belfast, is the UK's Innovation and Knowledge Centre developing novel solutions for securing digital assets, devices and citizens.

The institute provides a platform for academics, engineers, researchers, industry and government to accelerate the results of cyber and physical security research through to commercial application. Many multi-national partners have collaborated in its business-led projects including IBM, Intel/McAfee, Infosys and Cisco.


A leading European location

Not only can U.S. firms gain access to a well-educated and loyal workforce in Northern Ireland they can also take advantage of competitive costs, superspeed communications links to the U.S., support packages, a strong pro-business attitude and a great quality of life. In this vibrant welcoming place, academia, government and business work as partners to make things happen.

Find out more about what Northern Ireland has to offer your business visit, investni.com

Views

acclimated to it from many years of use, it becomes a part of our own selves in mind, body, and spirit.

This technology is only now becoming available for large numbers of people to use (see "Glass, Darkly," page 70). But it has already started to be banned in some places. For someone who has been inventing, designing, building, and wearing such devices for more than 30 years, and who founded MIT's wearable-computing project more than 20 years ago, being forbidden to use this technology feels like an affront to bodily integrity. These devices are not simply pieces of clothing or a variation on conventional eyewear. They have profound effects on how we see, understand, and remember the world.

As more people grow to depend on this technology in all facets of their lives (for example, as a memory aid or face recognizer), we must balance their rights with the desire to allow other people privacy and confidentiality. It is absurd to forbid people to remember things. Imagine an elderly gentleman being asked his whereabouts on a particular night, to which he replies, "I was not allowed to remember." We can't hold people responsible for their actions if we prevent them from doing what it takes to recall them.

My six-year-old daughter once asked me, "Why do buildings and cars have the right to wear a camera at all times, but people don't?" Our society has decided that organizations and businesses always have the right to use a camera for security, but the right to wear a camera as an assistive device seems less assured.

Let's value people at least as much as we do merchandise and elevate the wearable computer to the level of a security camera. We never forbid cameras to protect five-cent candies. So let's not forbid people to protect themselves with this same kind of technology. I have proposed legislation to protect the right of individuals to remember, computationally, what they experience.

As wearable computers and cameras become more widespread, we will certainly need to adopt new protocols and social attitudes toward the capture and sharing of visual information and other data. But these protocols should not include discrimination against users of these valuable assistive devices.

Steve Mann is chief scientist at the wearable-computing company MetaView and a professor at the University of Toronto.

MONEY

Bitcoin Economics

The digital cash lacks most of the features economists value in a currency, says David Yermack.

Bitcoin became a sensation in 2013, when the value of a single unit of the virtual currency rose from $13 to more than $1,000 and people began to use it for daily commerce (see chart on page 18). Travelers toured the world subsisting on bitcoins. A Bitcoin ATM appeared in a Vancouver coffee shop. And a U.S. Senate committee held hearings at which regulators commented favorably on Bitcoin and other virtual currencies.

Bitcoin is not issued by a government or a business but by computer code that runs on a decentralized, voluntary network. It has found users among computer enthusiasts and opponents of the banking system (see "Marginally Useful," page 80). However, economists remain skeptical of Bitcoin's staying power because it lacks many attributes of a useful currency. Money is supposed to serve three purposes: it functions as a medium of exchange, a unit of account, and a store of value. Bitcoin arguably satisfies the first criterion, because a growing number of merchants accept it as payment. But it performs poorly as a unit of account and a store of value.

Bitcoin's extreme fluctuations undermine any useful function for it in these roles. During 2013 its volatility was three to four times higher than that of a typical stock, and its exchange rate with the dollar was about 10 times more volatile than those of the euro, yen, and other major currencies. Bitcoin's dollar price exhibits no correlation with the dollar's exchange rates against other currencies. Nor does it correlate with the value of gold. With a currency whose value is so untethered, it is nearly impossible to hedge against risk.

Bitcoin also lacks additional characteristics usually associated with currencies. It cannot be deposited in a bank; instead it must be held in "digital wallets" that have proved vulnerable to thieves and hackers. There is nothing comparable to the deposit insurance relied on by banking consumers. No lenders use bitcoins as the unit of account for consumer credit, auto loans, or mortgages, and no credit or debit cards are denominated in bitcoins.

Even if volatility subsides and the currency finds a place in the world payments system, it has another fatal economic flaw. Only 21 million units can ever be issued, and a fixed money supply is incompatible with a growing economy. In a bitcoin-dominated economy, workers would have to accept pay cuts every year, and prices for goods would gradually fall. Such conditions might lead to public unrest reminiscent of the late 19th century's free-silver and populist movements—an ironic consequence of a currency known for its futuristic cachet.

David Yermack is a professor at the New York University Stern School of Business and director of the NYU Pollack Center for Law and Business.

PROFESSIONAL EDUCATION

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

YOUR DOOR TO MIT EXPERTISE & KNOWLEDGE

TRAINING & EDUCATION FOR PROFESSIONALS

Come to MIT for a Week

SHORT PROGRAMS

Register for a 2–5 day intensive course and gain critical knowledge to help advance your career and impact your company's success. Earn CEUs and a certificate of completion.

Each year approximately 40 courses are offered in a variety of subject areas (partial listing below):

- Biotechnology/ Pharmaceutical
- Crisis Management
- Data Modeling & Analysis
- Design, Analysis, & Manufacturing
- Energy/ Sustainability/ Transportation
- Imaging
- Information & Communication Technologies
- Innovation
- Leadership/ Negotiation
- Radar
- Robotics
- Systems Engineering
- Tribology

Come to MIT for a Semester

ADVANCED STUDY PROGRAM

Enroll in regular MIT courses through this non-matriculating, non-degree program. Participate on a full or part-time basis for one or more semesters.

As an Advanced Study Program participant you can:

- Advance your knowledge in the latest technologies and cutting edge research
- Learn from world renowned faculty
- Tailor studies to meet individual or company needs
- Choose from over 2,000 MIT undergraduate and graduate courses
- Earn grades, MIT credit, and a Certificate of Completion

Bring MIT to You

CUSTOM PROGRAMS

Enhance your organization's capabilities and expertise through customized programs tailored to meet your specific needs and priorities.

INTERNATIONAL PROGRAMS

Find out about regionally relevant MIT short courses being offered in various locations around the world.

To learn more about what MIT Professional Education can offer you and your company, visit us today at **HTTP://PROFESSIONALEDUCATION.MIT.EDU/TECHREVIEW** or email us at **PROFESSIONALEDUCATION@MIT.EDU.**

like mapping the genome was more than a science project

Valuable education, partnering, global networking, exhibits and entertainment makes **BIO 2014** much more than an event. The **BIO International Convention** regularly attracts 15,000 of the most powerful biotech and pharma players from 60+ countries, and every year we work to improve the experience. This year is no exception, with more networking, insight and opportunities delivering value to you and your business long after the event ends. Join us in San Diego and discover where BIO 2014 can take you.

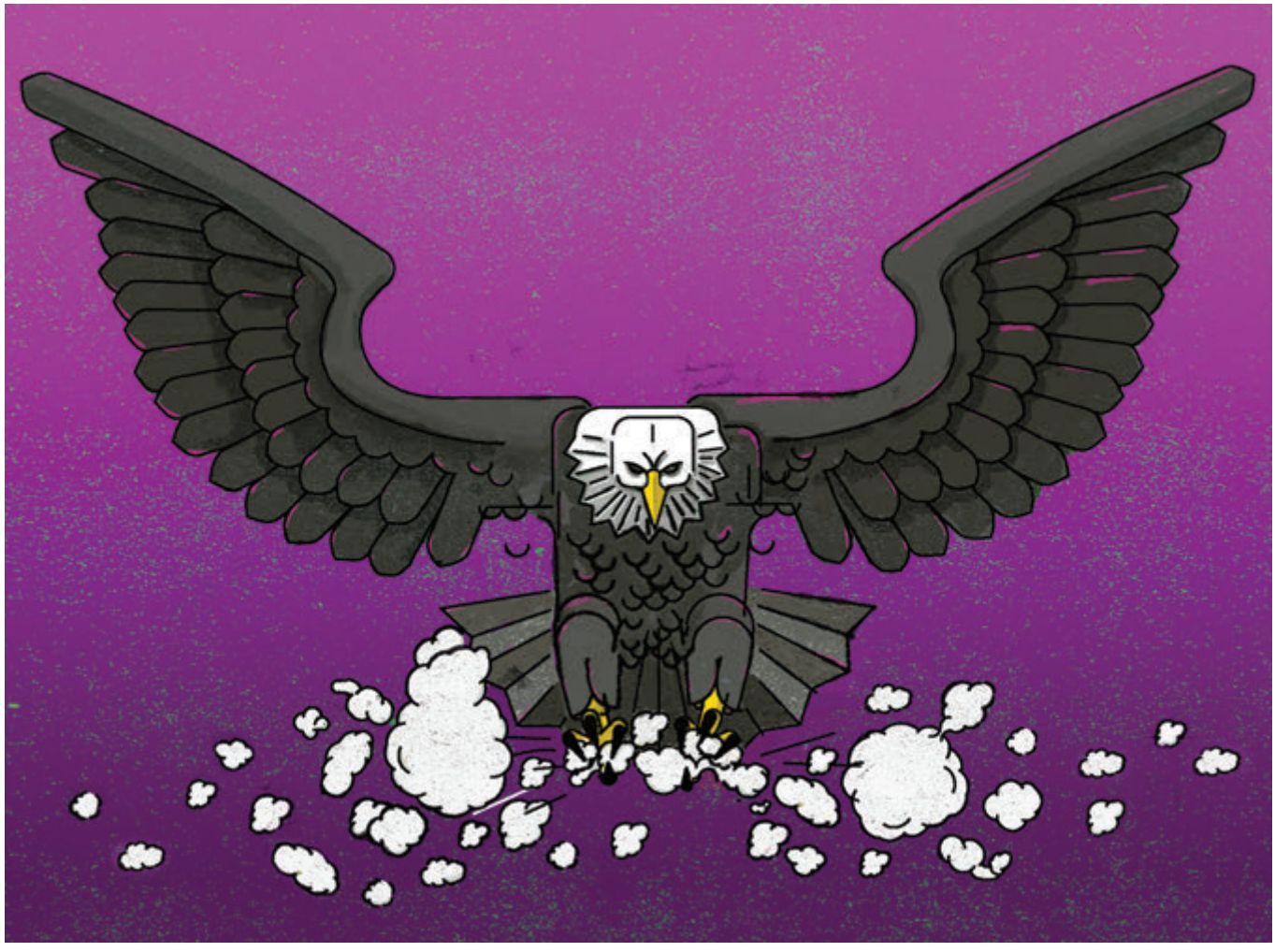
Register now. Early bird discount ends May 1.
convention.bio.org #BIO2014

BIO International Convention
The Global Event for Biotechnology

June 23–26, 2014
San Diego Convention Center
San Diego, CA

Bio

Upfront



YAREK WASZUL

For the Wary, an Alternative to Trusting the Cloud

The company behind BitTorrent offers software that replicates most features of file-synching services but keeps you in control of your data.

By Tom Simonite

The debate over how much we should trust cloud companies with our data was reawakened last year after revelations that the National Security Agency routinely harvests data from Internet companies including Google, Microsoft, Yahoo, and Facebook. BitTorrent, the company behind the sometimes controversial file-sharing protocol of the same name, is hoping this debate will drive adoption of its new file-synching technology.

Called BitTorrent Sync, it synchronizes folders and files on different computers and mobile devices much the way services like Dropbox do, but without ever copying data to a central cloud server.

Cloud-based file-synching services route all data via their own servers and keep a copy of it there. The BitTorrent software instead has devices contact one another directly over the Internet to update files as they are added or changed.

Upfront

QUOTED

"If someone cuts your finger off, you have bigger problems."

—Sebastian Taveau, former chief technology officer of Validity, on why fingerprint sensors make for better protection than passwords.

That difference in design means that people using BitTorrent Sync don't have to worry about whether the cloud company hosting their data is properly securing it against rogue employees or other threats.

Forgoing the cloud also means that the NSA or another agency couldn't harvest data shared using BitTorrent Sync without going directly to the person or company controlling the synched devices. Synched data does travel over the Internet, where it might be intercepted by a surveillance agency such as the NSA, but it travels in a strongly encrypted form. The drawback of BitTorrent Sync's design is that two devices must be online at the same time for them to synchronize, since there's no intermediary server to act as an always-on source.

BitTorrent Sync is available now as a free download for PCs and mobile devices, but in a beta version that is not as polished or easy to use as many other applications. BitTorrent CEO Eric Klinker says the next version, due this spring, will feature major upgrades that will make the software as user-friendly as established cloud-based competitors.

Klinker says BitTorrent Sync shows how popular applications can be redesigned to give people control of their own data, despite prevailing trends. "Pick any app on the Web today—it could be Twitter, e-mail, search—and it has been developed in a very centralized way; those businesses are built around centralizing information on their servers," he says. "I'm trying to put more power in the hands of the end user and less in the hands of these companies and other centralizing authorities."

Anonymous data sent back to BitTorrent by its software indicates that more than two million people are already using it each month. Some of those people have found uses that go beyond just managing files. For example, the company says one author in Beijing uses BitTorrent Sync to distribute blog posts on topics that provoke scrutiny from Chinese authorities. And one U.S. programmer built a secure, decentralized messaging system on top of the software.

"I'm trying to put more power in the hands of the end user," BitTorrent CEO Eric Klinker says.

Klinker says that companies are also starting to use BitTorrent Sync to avoid the costs of cloud-based solutions. He plans to eventually make the software pay for itself by finding a way to sell extra services to corporate users.

Given its emphasis on transparency and data ownership, BitTorrent has been criticized by some for not releasing the source code for its application. Klinker says he understands those concerns and may yet decide to do so.

Jacob Williams, a digital forensic scientist with CSR Group, says the current stance is defensible, although he generally considers open-source programs to be more secure. But finding subtly placed vulnerabilities in open-source software is still challenging, and the projects can be split off into different versions, which reduces the number of people scrutinizing any one version.

Williams's own research has shown how Dropbox and similar services could be used to slip malicious software through corporate firewalls. They are configured to use the same route as Web traffic, which usually gets a free pass. BitTorrent Sync is configured slightly differently, he says, but it "will likely require changes to the firewall in any moderately secure network."

TO MARKET

Gaze Gaming

EyeX

COMPANY:
Tobii Technology

PRICE:
$195

AVAILABILITY:
March

The EyeX from Swedish company Tobii Technology is intended to help game developers prepare for the release of the first eye-tracking videogame controller later this year. The EyeX uses infrared light and a camera to track the reflections from a player's pupils and determine the direction of his or her gaze. In demonstrations, this allowed game avatars to be guided by a player's eyes and let players change their on-screen weaponry simply by looking at a listed option. The same technology will appear this summer in a game controller made by Tobii in partnership with SteelSeries, which makes gaming peripherals. When the game controller launches, it will bring eye-tracking capabilities to approximately 100 games.

COURTESY OF TOBII (GAZE); COURTESY OF SYNAPTICS (TAVEAU)

WHAT WILL THE FUTURES BRING?

TWELVE TOMORROWS

—

Visionary stories of the near future inspired by today's new technologies

—

The second science fiction anthology from the editors of *MIT Technology Review*

—

Available for iPad, Kindle, NOOK, or as a limited edition printed volume

—

Learn more:
TechnologyReview.com/12Tomorrows

MIT Technology Review

Upfront

Show Me the Bitcoins

The digital currency Bitcoin is gaining momentum. Though still volatile, its value has been surging as more bitcoins are being spent than hoarded. And the currency's popularity has spawned many competitors.

1 FEBRUARY 2011
The market price of a bitcoin surpasses $1 for the first time.

2 JUNE 2011
Press reports on Silk Road, where bitcoins could buy illegal drugs, draw attention to the currency, and the value of a bitcoin spikes.

3 JUNE 2011
The price of a bitcoin reaches $30, then falls after the largest Bitcoin exchange, Mt. Gox, is hacked.

4 FEBRUARY 2013
The popularity of bitcoin gambling websites grows, and the price of a bitcoin surpasses $30.

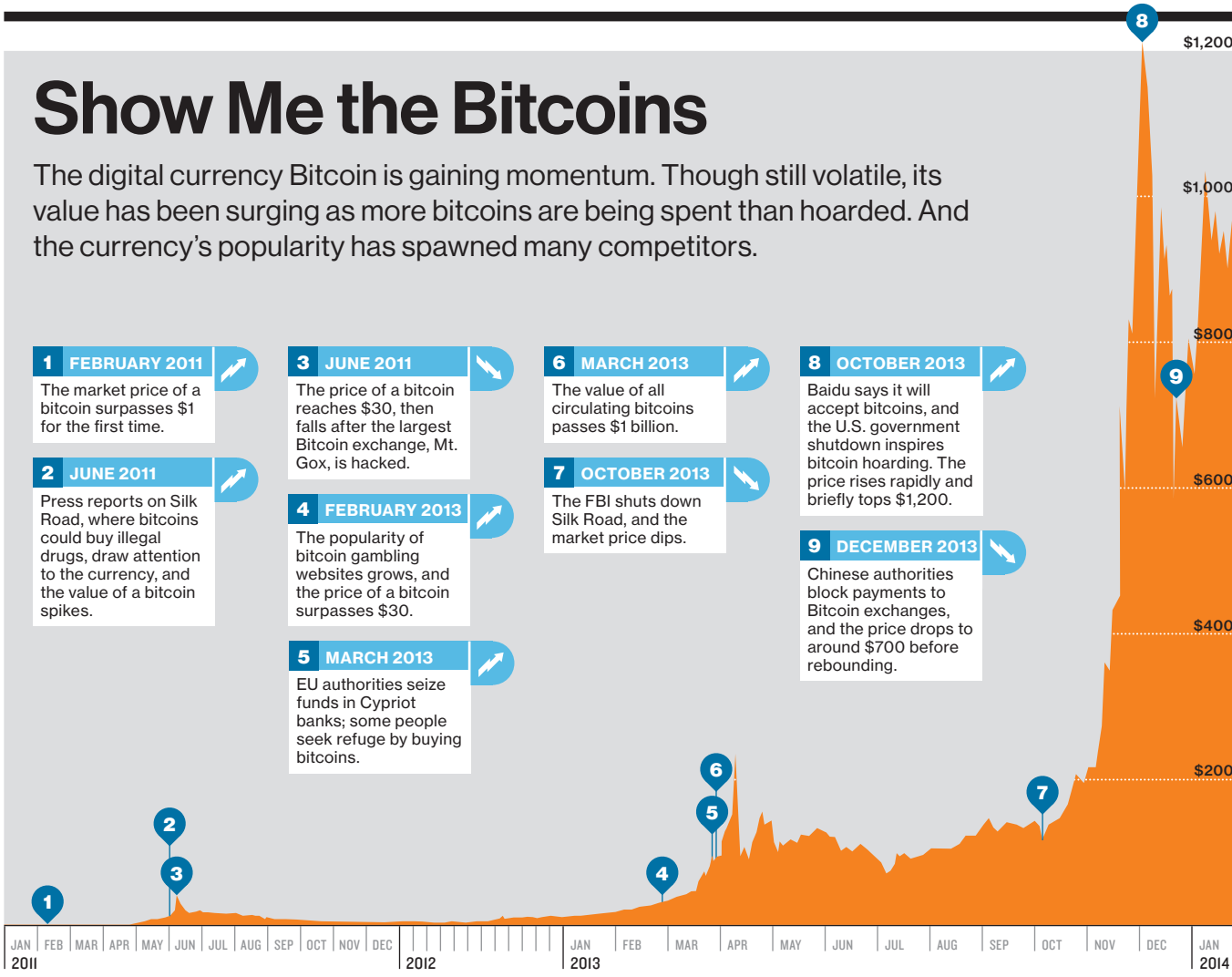
5 MARCH 2013
EU authorities seize funds in Cypriot banks; some people seek refuge by buying bitcoins.

6 MARCH 2013
The value of all circulating bitcoins passes $1 billion.

7 OCTOBER 2013
The FBI shuts down Silk Road, and the market price dips.

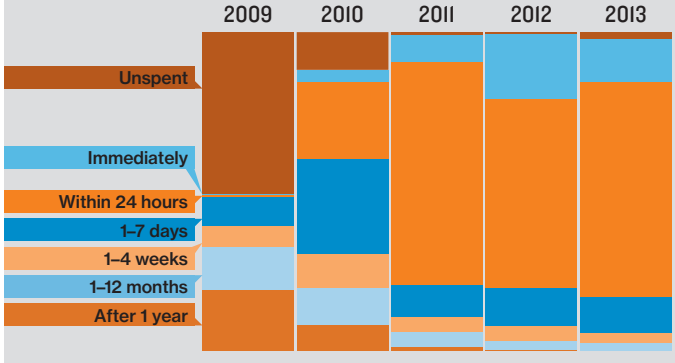
8 OCTOBER 2013
Baidu says it will accept bitcoins, and the U.S. government shutdown inspires bitcoin hoarding. The price rises rapidly and briefly tops $1,200.

9 DECEMBER 2013
Chinese authorities block payments to Bitcoin exchanges, and the price drops to around $700 before rebounding.



How fast are people spending bitcoins?

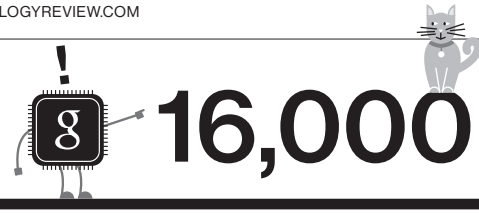
New bitcoins are now far more likely to be spent than hoarded by speculators.



Physical cash vs. digital money

Just the U.S. bills and coins in circulation are enough to dwarf the value of digital currencies.

Ripple	$2.1 billion
Litecoin	$560 million
Peercoin	$111 million
Nxt	$70 million
Dogecoin	$53 million



16,000

The number of chips Google used to teach its deep-learning software to recognize cats in YouTube videos

A Brain-Inspired Chip Helps Smartphones Spot Faces

Hardware created to run neural networks will help smartphones make sense of the world.

By Tom Simonite

A powerful approach to artificial intelligence could be coming to smartphones. Researchers from Purdue University are working to commercialize designs for a chip meant to help mobile processors make use of the AI method known as deep learning. Google, Facebook, and Baidu have invested in deep-learning technology, but so far it has been limited to large clusters of high-powered computers. When Google developed software that learned to recognize cats in YouTube videos, for instance, the experiment required 16,000 processors.

Being able to implement deep learning in more compact and power-efficient ways could lead to smartphones and other mobile devices that can understand the content of images and video, says Eugenio Culurciello, a Purdue professor who is working on the project. In December, at the Neural Information Processing Systems conference in Nevada, the group demonstrated that a co-processor connected to a conventional smartphone processor could help it run deep-learning software. The software was able to detect faces or label parts of a street scene. The co-processor's design was tested on an FPGA, a reconfigurable chip that can be programmed to test new hardware designs. The prototype is less powerful than Google's cat detector, but it shows how new forms of hardware could make it possible to use the power of deep learning more widely. "There's a need for this," says Culurciello. "You probably have a collection of several thousand images that you never look at again, and we don't have a good technology to analyze all this content."

Deep learning could let smartphones understand the content of images.

Devices such as Google Glass could also benefit from the ability to understand the many pictures and videos they are capturing. A person's images and videos might be searchable using text—"red car" or "sunny day with Mom," for example. Likewise, novel apps could be developed that take action when they recognize particular people, objects, or scenes.

Deep-learning software works by filtering data through a hierarchical, multilayered network of simulated neurons that are individually simple but can exhibit complex behavior when linked together. Computers are inefficient at simulating those networks because the networks are very different from conventional software. Purdue's co-processor design is specialized to run multilayered neural networks and put them to work on streaming imagery. In tests, the prototype has proved about 15 times more efficient than a graphics processor for the same task, and Culurciello believes that improvements could make the system 10 times more efficient than it is now.

Narayan Srinivasa, director of the center for neural and emergent systems at HRL Laboratories, a research lab jointly owned by Boeing and General Motors, says it makes sense to use separate hardware to implement deep learning because, like real neural networks, it can intertwine memory and processing. His own research focuses on addressing that problem with a more extreme solution: designing chips with silicon neurons and synapses that mimic those of real brains. Culurciello has started a company, called TeraDeep, to commercialize his own designs.

ILLUSTRATION ON OPPOSITE PAGE BY WALTER BAUMANN. DATA: MTGOX, BLOCKCHAIN.INFO, BITCOINCHARTS.COM, COINMARKETCAP.COM; SARAH MEIKLEJOHN (BITCOIN SPENDING). U.S. FEDERAL RESERVE (BILLS AND COINS); CURRENCY VALUES AS OF JANUARY 28. PHOTO THIS PAGE COURTESY OF 3M.

TO MARKET

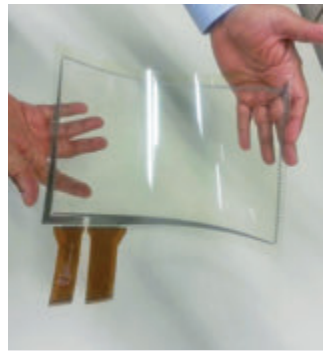
Smarter Screens

3M Patterned Silver Nanowire Film

COMPANY:
3M

PRICE:
Not disclosed

AVAILABILITY:
Now

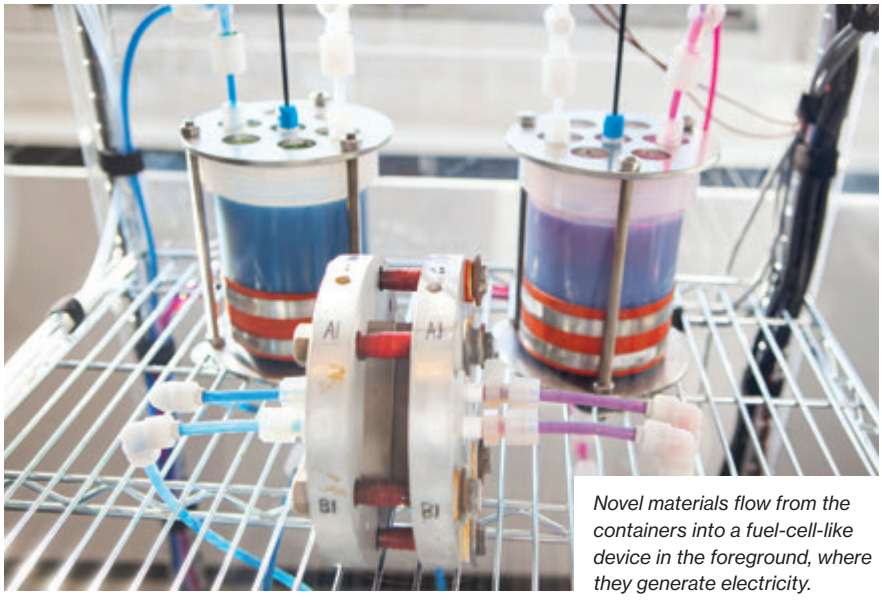


Touch screens could become larger and more flexible thanks to these transparent films made of silver nanowires. The films, which 3M is producing for device makers, use nanotechnology from a startup called Cambrios. Its wires, which are a few nanometers in diameter and a few micrometers long, come suspended in inks; Cambrios claims that electrodes made from these inks are more conductive and transparent than the most commonly used materials and can be rolled and unrolled more than 100,000 times without breaking, making curvy or foldable devices possible. In contrast, today's touch screens are made of brittle indium tin oxide films, which limits their size and design.

Upfront

$100

The price per kilowatt-hour that the DOE says would make storing energy from wind farms economical



Novel materials flow from the containers into a fuel-cell-like device in the foreground, where they generate electricity.

Battery Material Could Help Wind and Solar Power Scale Up

Low-cost materials could make storing hours of power from a wind farm economically feasible.

By Kevin Bullis

Utilities would love to be able to store the power that wind farms generate at night and use it when demand is high during the day. But conventional battery technology is so expensive that it only makes economic sense to store a few minutes of electricity.

Harvard University researchers say they've developed a new type of battery that could make it economical to store a couple of days' worth of electricity from wind farms and other sources. The new battery is based on an organic molecule—called a quinone—that's found in plants such as rhubarb and can be cheaply synthesized from crude oil. The molecules could reduce by two-thirds the cost of the materials in a type of battery called a flow battery, which is particularly well suited to storing large amounts of energy.

In a flow battery, energy is stored in liquid form in large tanks. Such batteries have been around for decades, but they're expensive—they cost about $700 per kilowatt-hour of storage capacity, according to one estimate. To make storing hours of energy from wind farms economical, batteries need to cost just $100 per kilowatt-hour, according to the U.S. Department of Energy.

Michael Aziz, a professor of materials and energy technologies at Harvard University, who led the work, says the quinones will cut the cost of energy storage materials down to just $27 per kilowatt-hour. Combined with other recent advances that have brought down costs for the rest of the system, he says, this could put the DOE target in reach.

The Harvard work is the first demonstration by researchers of high-performance flow batteries that use organic molecules instead of the metal ions usually used. The quinones are easily modified, which might make it possible to improve their performance and reduce costs further. "The options for metal ions were pretty well worked through," Aziz says. "We've now introduced a vast new set of materials."

After identifying quinones as potential energy storage molecules, the Harvard researchers used high-throughput screening techniques to sort through 10,000 variants, searching for ones that had all the right properties for a battery—the right voltage levels, the ability to withstand charging and discharging, and the ability to be dissolved in water so they could be stored in liquid tanks. So far the researchers are using quinones only for the negative side of the battery. The positive side uses bromine, a corrosive and toxic material. The researchers are developing new versions of the quinones that could replace the bromine. They are working with the startup Sustainable Innovations to develop a battery as big as a horse trailer, which could be used to store power from solar panels on commercial buildings.

Currently, it only makes economic sense to store a few minutes of electricity.

The researchers face competition from other startups developing cheaper flow batteries, such as EnerVault and Sun Catalytix. EnerVault uses iron and chromium as its storage materials. Sun Catalytix is developing inorganic molecules to improve performance and lower cost.

COURTESY OF ELIZA GRINNELL, HARVARD SCHOOL OF ENGINEERING AND APPLIED SCIENCES

Smart Radios Reduce Smartphone Battery Drain

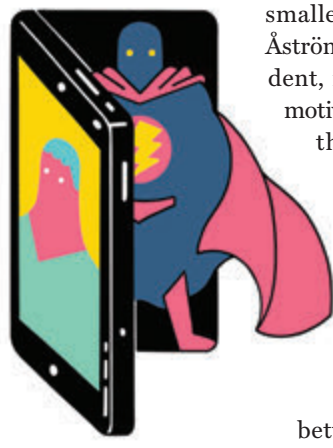
The battle between device makers is moving from software to hardware.

By David Talbot

The wireless industry faces a fundamental problem: more features and faster data transmission are draining phone batteries faster than ever.

Fortunately, there's room for improvement inside the devices, in parts known as power amplifiers that turn electricity into radio energy. In phones, these parts typically consume more power than any other component and waste half of it along the way.

Now an effort is under way to develop power amplifiers that significantly reduce waste. Eta Devices, an MIT spinoff based in Cambridge, Massachusetts, is preparing a base station module and a chip that it says not only decrease battery drain but work well in high-bandwidth applications for ultrafast technologies.



Existing power amplifiers maintain their voltage at a fairly high level at all times to be prepared for peak needs—but this is wasteful. Newer approaches adjust that level on the fly, following the "envelope" of the actual radio signal.

Such "envelope tracking," or ET, technologies are the hottest hardware development in the mobile-phone industry. Last fall Qualcomm became the first company to ship a chip with such technology. The company says the chip helps lower electricity consumption by 20 percent and helps reduce a related problem—heat generation—by up to 30 percent, "allowing for longer battery life for end users, as well as enabling manufacturers to shrink the size of their devices," says Peter Carson, Qualcomm's senior director of marketing.

The difficulty with ET, though, is that its efficiency plunges at higher data rates. Envelope trackers often require a relatively large capacitor to store and release bursts of energy while maintaining smooth and continuous voltage changes.

Eta Devices takes a radically different approach, favoring fast, abrupt changes with a smaller capacitor. Mattias Åström, the company president, reaches for an automotive analogy to compare the two approaches. "Envelope tracking is basically a continuous variable transmission, compared to our manual gearbox," he says. "Fuel consumption is always better when you have a manual gearbox."

The chip is now being fabricated for the first time, but the concept has been built out for base stations and may be commercialized this year. The Eta module, a little smaller than a shoebox, is the first 4G LTE transmitter in the world to achieve average efficiency greater than 70 percent, a big jump from the 45 to 55 percent in currently available technology, says Eta cofounder Joel Dawson.

SAM ISLAND, COURTESY OF GOOGLE (KUFFNER)

3 QUESTIONS

James Kuffner

At a military contest in Miami, a Google scientist discusses the future of robotics.

What can you tell me about why Google bought Boston Dynamics and several other robotics companies?
Nothing right now.

Well, what do you find exciting about this contest?
I think setting up these challenges is a good way to motivate people to work on hard problems and bring together the best hardware and software to make these machines do useful tasks. It's going to take a lot of hard work to make these robots achieve the same level of performance and agility that humans and animals have. I think that's something to motivate everyone.

Is this technology at an earlier stage than the self-driving cars at previous DARPA challenges?
The original DARPA challenge for autonomous vehicles basically came down to waypoint following and GPS, and then of course as it progressed to the Urban Challenge it became much more complicated. [At this challenge], these tasks certainly may look easy, especially for a human, but they're very, very difficult. You can't yet buy these robots, so they're very much research prototypes. But I feel like in the last 20 years there's been incredible acceleration, and I'm really excited to see this much effort and attention being paid to try and make the robots do something practical. *—Will Knight*

Upfront

500,000,000

Gallons of water that a proposed solar-thermal power plant in California would have used each year

Twitter Cofounder Wants You to Ask More Questions

His smartphone app Jelly makes it easy to get your friends' advice on everything from shopping to Chopin.

REVIEW

THERE ARE PLENTY OF PLACES TO SEEK answers to questions, including search engines like Google and Q&A sites like Quora. Now Jelly, a startup created by Twitter cofounder Biz Stone, is squishing its way into the fray with a free smartphone app that lets you ask questions attached to images and give answers to people in your extended social network.

Like Twitter, which faced much skepticism early on, Jelly has plenty of folks raising an eyebrow in its direction while trying to figure out what it's good for.

I spent two days trying out Jelly on my iPhone (it's available for iOS and Android right off the bat). Getting started is simple: after you connect your Facebook and Twitter accounts, you'll see a question in search of answers from one of your friends dominating the display, and you can tap to add an answer or read existing answers. If you want to ask a question, you have to take or import a photo, type a question, and submit it.

Jelly will alert you when you receive an answer or someone "likes" an answer you supplied. You can send other users virtual thank-you notes for their answers.

I had a hard time figuring out what to ask early on, and I think many other users were (and are) in the same boat, as indicated by the overabundance of questions like "What airport am I in?" I spent a lot of time flicking away questions that didn't deserve an answer.

After a while, though, I started to see that much of Jelly's potential lies in its ability to quickly gather a chorus of opinions on everything from music and shopping to pet and plant care. As users figure this out, I expect the ratio of silly to earnest questions to improve.

When I asked questions like "Is it worth hiring a wedding photographer?" I got many helpful responses, including some links to local photographers.

I noticed others experimenting with Jelly's recommendation potential, too. One guy wanted to know which shoes he should wear with his paisley shirt, while another asked about buying a cheap fixed-gear bike. I gave my opinion on David Foster Wallace's epic *Infinite Jest* and shared my surreal experience of watching US Airways Flight 1549 float down the Hudson River in 2009. I felt a little thrill each time an alert informed me that someone had marked my answer as "good."

Still, Jelly really needs some other features. There is no categorization system for questions, there's no way to search, and, as many users noted, there's no "back" button within the app. There also doesn't seem to be an organized way to see only the questions you've asked or answered.

Perhaps more important, Jelly needs to improve its ability to determine which questions you should see, so it can make it more likely that you'll offer helpful answers and contribute your own questions. The app already uses an algorithm for this, but amassing a significant volume of data for it to learn from could take some time. In the meantime, I expect to keep seeing lots of questions about football teams, iPhone app organizing, and almond butter.

—Rachel Metz

Questions
Users are encouraged to post questions to their friends.

Snapshot
An image must be included with all posts, which may encourage users to post while shopping.

Answers
Responses to questions appear in tiles below.

RACHEL METZ | MIT TECHNOLOGY REVIEW

UNPLUGGED **PRODUCTIVITY**

NeatConnect®

CLOUD SCANNER + DIGITAL FILING SYSTEM

Do more in less time.

NeatConnect lets you send scanned items straight to your favorite cloud services and more. You can even send scans as emails – all without ever turning on a computer.

Work wherever you want.

Put NeatConnect where your paper is. Its integrated Wi-Fi and touchscreen interface let it do its job from virtually any room in the house, or any spot in the office.

Simplify your life.

Neat streamlines your day-to-day workflow and gives you more time to do what you want. Find any document fast, organize everything digitally, and stop wasting time with paper.

NEATCONNECT SCANS DIRECTLY TO:

NeatCloud® SkyDrive box EVERNOTE Dropbox Google Drive

neat®

Order NeatConnect now & get **3 FREE MONTHS of NeatCloud**

▸ Call **866-395-4805** ▸ Visit **www.neat.com/review**

Upfront

QUOTED

"I don't necessarily want a cloud service to know every single time I walk in and out of my front door."

—Liat Ben-Zur, head of Qualcomm's AllJoyn unit, on the drawbacks of Internet-connected door locks.

Hacking the Immune System to Lessen Heart Attack Damage

Microparticles that block the body's immune response to damaged tissue could help prevent further harm.

By Mike Orcutt

Using tiny biodegradable particles to disrupt the body's immune response after a heart attack could help save patients from tissue damage and certain long-term health problems that often follow.

Researchers have shown that injecting such particles into mice within 24 hours of a heart attack not only significantly reduces tissue damage but also leaves those mice with stronger cardiac function 30 days later.

Much of the tissue damage that results from a heart attack is due to inflammation, the body's natural response to harmful stimuli such as muscle damage. But in the case of a heart attack, the resulting immune cells do more harm than good, explains Daniel Getts, inventor of the new therapy and chief scientific officer of Cour Pharmaceutical Development.

While the compounds that the immune cells secrete can be beneficial in defending the body against an infection, they also cause tissue damage. This phenomenon occurs in a range of other diseases as well, including West Nile virus and multiple sclerosis.

The 500-nanometer particles must be negatively charged and can be made of several different materials, including the one used for biodegradable sutures. The new research suggests that once the particles are in the bloodstream, the negative charge attracts a specific receptor on the surface of inflammatory monocytes. The particles bind to that receptor and divert the immune cells away from the heart and toward the spleen, where they die.

The nanoparticles divert immune cells away from the heart and toward the spleen, where they die.

Preventing these cells from reaching the heart allows the damaged muscle to regenerate "along more regulated processes," says Getts. Should the therapy translate to humans, he says, it could substantially reduce the complications that some heart attack patients experience, including shortness of breath and limited ability to exercise. The goal is to begin human tests by early next year, and the company hopes that the simple mechanism of the therapy will speed the development process.

However, "there is still some homework to do," says Matthias Nahrendorf, a professor of systems biology at Harvard. In particular, researchers will have to tease out any side effects the microparticles might produce. The particles may activate the immune system in some yet-unknown way, he says. In addition, Nahrendorf says, it will be important to determine how to administer the therapy so that it doesn't compromise the cells' ability to aid healing and defend the body against infections and other invaders.

TO MARKET

Ticker Tracking

AliveInsights

COMPANY:
AliveCor

PRICE:
$2 to $12 per consult

AVAILABILITY:
Now

Those concerned about the health of their heart can now get expert consultations by smartphone. AliveCor, a company that already makes an electrocardiogram device that plugs into an iPhone or Android device, has launched a service that connects patients to experts who will analyze their cardiac rhythms for a small fee. The system sends a person's EKG data to a cardiologist or technician via a smartphone app. It then delivers an analysis of the data within 30 minutes to 24 hours, depending on the service selected. Readings from AliveCor's device are less accurate than those from a 12-lead EKG machine, but reports can be sent to a doctor for further analysis.

COURTESY OF QUALCOMM (BEN-ZUR); COURTESY OF ALIVECOR (APP)

FREDRIK BRODEN

The 50 Smartest Companies 2014

IT MIGHT SOUND DIFFICULT TO DEFINE what makes a smart company, but you know one when you see it. When such a company commercializes a truly innovative technology, things happen: leadership in a market is bolstered or thrown up for grabs. Competitors have to refine or rethink their strategies.

This is what the editors of *MIT Technology Review* looked for as we assembled this list. We didn't count patents or PhDs; instead, we asked whether a company had made strides in the past year that will define its field. The biggest of these strides happened at Illumina, which is driving down the price of DNA sequencing to levels that will change the practice of medicine. We also found dramatic developments on the Web, in batteries, and even in agricultural technologies.

Familiar names such as Apple and Facebook aren't on this list because reputation doesn't matter. We're highlighting where important innovations are happening right now.

These businesses are setting the pace of innovation. They're shaking up markets or creating new ones.

1

Illumina

See story on p. 28.

2

Tesla Motors

See story on p. 30.

3

Google

See story on p. 32.

4

Samsung

Maximizing the advantages of its vertical integration as it extends its lead in the smartphone market.

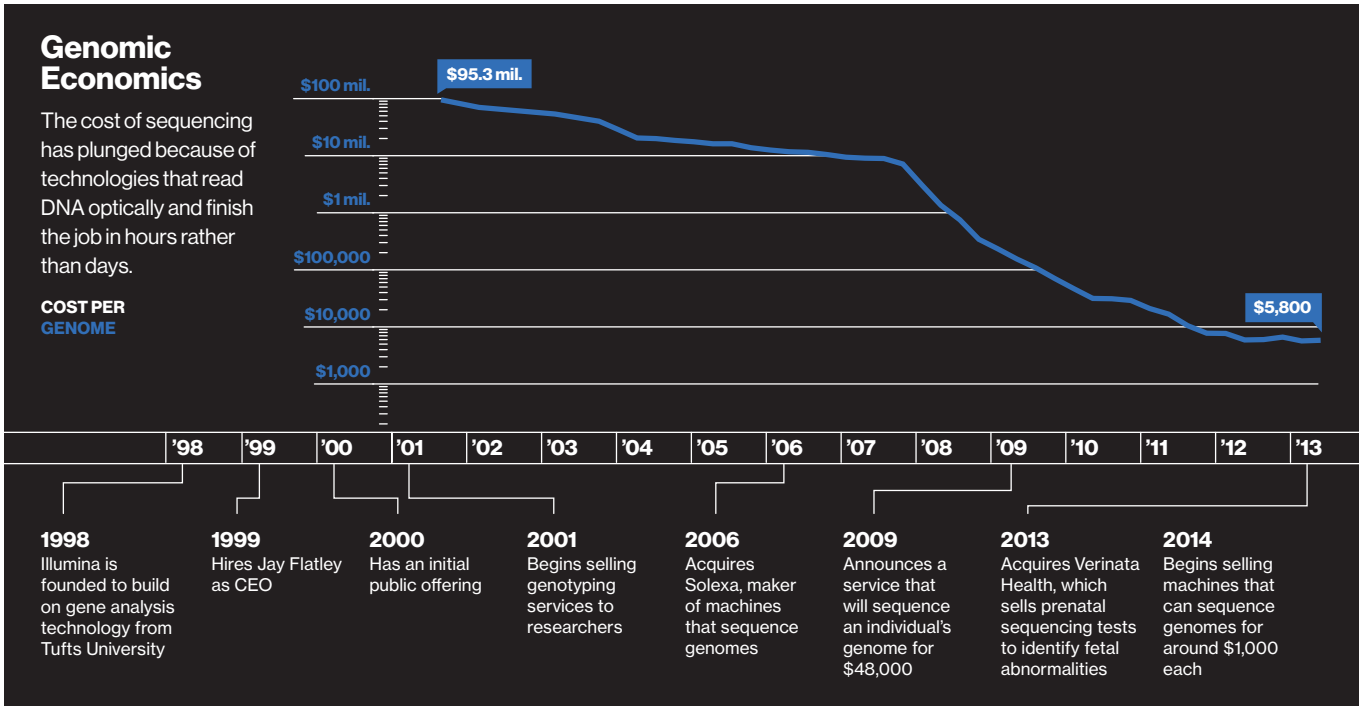
32 percent: Samsung's share of global smartphones sold

5

Salesforce.com

Its tools will be crucial in helping companies incorporate new data from the Internet of things.

2,150: number of business apps in Salesforce's online marketplace



Illumina

After outflanking and outlasting competitors, it is on top of the genome-sequencing business—just as that market is about to soar in importance.

1 ALMOST 25 YEARS AFTER THE Human Genome Project launched, and a little over a decade after it reached its goal of reading all three billion base pairs in human DNA, genome sequencing for the masses is finally arriving. It will no longer be just a research tool; reading all of your DNA (rather than looking at just certain genes) will soon be cheap enough to be used regularly for pinpointing medical problems and identifying treatments. This will be an enormous business, and one company dominates it: Illumina. The San Diego–based company sells everything from sequencing machines that identify each nucleotide in DNA to software and services that analyze the data. In the coming age of genomic medicine, Illumina is poised to be what Intel was to the PC era—the dominant supplier of the fundamental technology.

Illumina already held 70 percent of the market for genome-sequencing machines when it made a landmark announcement in January: using 10 of its latest machines in parallel makes it feasible to read a person's genome for $1,000, long considered a crucial threshold for moving sequencing into clinical applications. Medical research stands to benefit as well. More researchers will have the ability to do large-scale studies that could lead to more precise understanding of diseases and help usher in truly personalized medicine.

Illumina was relentless in getting to this point. When CEO Jay Flatley joined the company in 1999, it was a 25-person startup that sold microarray chips, which were useful in examining specific spots on the genome for important variations. But while the market grew relatively fast, competition was tough. In 2003, for example, Illumina had $28 million in revenue and a net loss of $27 million. Making matters tougher, the potential for microarrays seemed limited once more comprehensive sequencing technology began to improve quickly. In 2006, when a company called 454 Life Sciences was months away from the first rapid readout

CHART BY INFOGRAPHICS.COM. DATA FROM NATIONAL HUMAN GENOME RESEARCH INSTITUTE

← The cost of sequencing has fallen faster than the cost of computing.

of an individual human genome (that of DNA scientist James D. Watson), Flatley knew Illumina had to have a sequencing technology of its own, and he had a choice: build it or buy it. "We had an internal development program, but we were also looking at anyone in the market that already had a sequencing technology," he says now. Ultimately he settled on buying a company called Solexa.

Solexa took advantage of a novel way of sequencing, known as sequencing by synthesis, that was 100 times faster than other technologies and correspondingly cheaper, says Flatley. But it was a small business, with just $2.5 million in revenue in 2006. After Illumina provided the global distribution Solexa needed, "we built it into a $100 million business in one year," he says. "It was an inflection point for us. We began this super-rapid growth."

The deal also turned out to be a turning point for Illumina's competitors, which quickly fell behind technologically. Roche, which bought 454 Life Sciences in 2007, announced last October that it would shutter the company and phase out its sequencers. Complete Genomics, another competitor, cut jobs and began looking for a buyer in 2012; last year the Chinese company BGI-Shenzhen bought it, although Illumina made a failed bid for it as well.

The Solexa deal was far from the last time that Flatley transformed Illumina by buying the technology he thought it needed. Another pivotal point came last year, when the company bought Verinata Health, maker of a noninvasive prenatal sequencing test to identify fetal abnormalities. That gave Illumina a service that consumers can buy (through their doctors), in a market that could be worth billions of dollars in revenue.

Since 2005 Illumina has spent more than $1.2 billion on acquisitions. But it would be a mistake to dismiss the company as just a deep pocket. Illumina has a knack for improving the technology of companies it buys, says Doug Schenkel, managing director for medical technology equity research at Cowen and Company. When Illumina bought Solexa's sequencing technology, Schenkel says, it was considered inflexible and was thought likely to hit a "ceiling"—after which it could probably not be improved further—within three years. "Illumina took that technology and, with innovation and investment, has made it flexible enough to not only dominate existing markets but open up multiple new opportunities," he adds. "Even today—six years later—the ceiling is still at least three years away."

Illumina's soup-to-nuts strategy—of providing fundamental sequencing technologies as well as services that mine genomic insights—appears to be a winner as genomic information begins to touch the practice of medicine and enter everyday life. Illumina already has an iPad app that lets you review your genome if it has been analyzed. "One of the biggest challenges now is increasing the clinical knowledge of what the genome means," Flatley says. "It's one thing to say, 'Here's the genetic variation.' It's another to say, 'Here's what the variation means.'" Demand for that understanding will only increase as millions of people get sequenced. "We want to be at the apex of that effort," he says.

—Eilene Zimmerman

6

Dropbox

Its business services are making cloud file storage more pervasive.

200 million: number of users

7

BMW

At the forefront of adding self-driving capabilities to cars.

2020: when BMW expects to begin selling cars that are autonomous on highways

8

Third Rock Ventures

See story on p. 34.

9

Square

Not just giving merchants a way to collect payments on phones; now you can e-mail someone money.

$20 billion: estimated annual value of transactions processed by Square

10

Amazon

Raising expectations for what e-commerce can deliver.

12: the number of top online retailers whose sales would have to be combined to match Amazon's

11

Tencent

Building on its Twitter-like social-media service in China with electronic payment technologies.

$130 billion: Tencent's market capitalization

12

Snapchat

Meeting the need for online interactions that are ephemeral.

$3 billion: size of buyout offer from Facebook, which Snapchat rejected

13

Cree

See story on p. 36.

14

Box

Its online file storage service is becoming the basis for a wide range of applications that help people get work done.

1,000: number of third-party mobile apps that work with Box

Tesla Motors

2

Car companies have struggled to sell electric cars. Tesla Motors is the exception. Last year, the first full year of sales for its Model S luxury sedan, Tesla sold more than twice as many cars as either Nissan or GM did when they introduced their battery-powered vehicles, the Leaf and the Volt. Tesla did this even though it's a startup with no dealer network, selling a car that's more than twice as expensive as the electric cars from the major automakers.

It's easy to be dazzled by the car's style or features like its 17-inch touch screen. But the innovation goes much deeper than that. *MIT Technology Review*'s senior editor for energy, Kevin Bullis, asked JB Straubel, Tesla's cofounder and chief technical officer, to help identify the engineering advances behind Tesla's success.

Other electric-car startups—such as Fisker Automotive—have failed. And even established automakers have struggled to sell their battery-powered cars. What makes you different?
Part of it is that Tesla designs its own batteries, motors, electronics, and software controls. It's not very glamorous, and not even always customer facing, but in the end that's what makes the car work and what makes it different from other electric cars, and makes it compete effectively against gasoline cars.

An example?
Our superchargers allow us to charge the Model S more than twice as fast as other cars. To do that kind of charging, everything has to be working in perfect synchrony. The cooling system; the electronics that are talking to the charger; the connection to the grid. That whole thing has to work as a system flawlessly. If we outsourced the charger, or outsourced those other pieces, we couldn't innovate as quickly. We couldn't roll out things anywhere near as fast.

You made an early decision to switch from analog to digital controllers for the electric motor, which allows you to control the motor with software. How important was that decision?
Even we didn't understand, in the early days, how much flexibility and agility that would give us.

There was a lot of hand-wringing, and it was a difficult decision to make the leap from the old pathway over to the new and really bet everything on it. But that decision set us up to put software in control of all of the key vehicle functions, and we are now unique in our ability to change those things remotely.

You're referring to wireless updates. Last year two Model Ss caught fire after drivers ran over objects in the road. Tesla sent out a software patch that raised the height at which the cars travel on the highway. There have been no car fires since.
I'm totally convinced that the entire industry will go in this [wireless] direction. It's only a matter of time.

QUICKHONEY

JB Straubel, 38
CTO, Tesla Motors
Palo Alto, California

"We're on track to getting to costs that will allow us to make a $35,000 car with a greater-than-200-mile range. It doesn't require some mythical invention. All the pieces are fundamentally there." —JB Straubel

You made an early decision to use small batteries, similar to the kind used in laptops, that cost less per kilowatt-hour of storage than the cells other automakers use. But whereas other automakers might have a few hundred battery cells in a pack, you have to use 10,000.

Other car companies think that large-format cells must be the way to go. But they're more expensive and have worse performance. People think of thousands of cells and say, "I don't know how to do that, and I don't want to think about that." It is a challenging problem. It's harder to engineer a system to do it, but engineering is a one-time difficulty.

We started with a commodity [laptop] cell because we had 50 people and we couldn't do anything else. But that plan has evolved. We're now to the point that we're working extremely closely with the cell manufacturers in designing customized cells with customized chemistry for cars.

You've used lower-cost cells, but because you chose to give your cars a 250-mile range, compared with less than 100 miles for most of your competitors' cars, your cars are still expensive—people are paying $70,000 to over $100,000 per car.

People think the battery accounts for most of the cost of an electric car, but that's not the case at all. For the Roadster [Tesla's first car], the battery was already down below half the cost. Now we're down to a quarter of the cost in most cases. We're on track to getting to costs that will allow us to make a $35,000 car [the cost of the GM Volt] with a greater-than-200-mile range. It doesn't require some mythical invention. All the pieces are fundamentally there.

15

BrightSource Energy

Fired up the world's largest solar thermal power plant, in California.

377 megawatts: the plant's production when fully operational

16

Wal-Mart Stores

Taking advantage of its retail heft as it rethinks payment and e-commerce technologies.

1 billion: Walmart.com page views in first five days of holiday season

17

General Electric

Its use of big data and sensors could help revive manufacturing.

$1.5 billion: announced investment in the "industrial Internet"

18

Qualcomm

Making breakthroughs in "neuromorphic" computing.

30 percent: 2013 revenue growth

19

Kaggle

Has helped many organizations crowdsource data analysis; now focusing on certain industries.

144,000: number of registrants for Kaggle data-analysis competitions

Google

The company has struggled to move beyond advertising. Has it finally found the missing piece?

3

WHEN IT COMES TO DEVELOPING software, few companies can match Google's prowess. It doesn't just have the most popular search engine. Chrome is the most widely used Internet browser. Gmail, Calendar, Spreadsheets, Docs, and Presentations are legitimate alternatives to Microsoft Office. Picasa, Google's free photo management software, might be as good as anything from Apple. Android dominates the phone and tablet landscape. Google Maps is becoming the best navigation program on any device.

And yet by one important measure, Google hasn't been innovative enough. The vast majority of its revenue comes from ads—the ones in search results and the ones that Google pushes out to thousands of websites. These were amazing innovations when Google developed them back in 2001 and 2002. But Google's many efforts to develop additional ways to make money haven't gone very far.

Perhaps Google's most public failures have been in consumer electronics. Do you remember Google TV? The Nexus One? The Nexus Q? If you do, it's probably not because you bought one. Google acquired Motorola Mobility for $12.4 billion in 2012 in an effort to finally build products that consumers wanted to buy. But Motorola's market share *fell* on Google's watch; the deal soured so fast that Google is now selling off most of Motorola to Lenovo. In the end Google will have spent about $3 billion to get a chunk of Motorola patents.

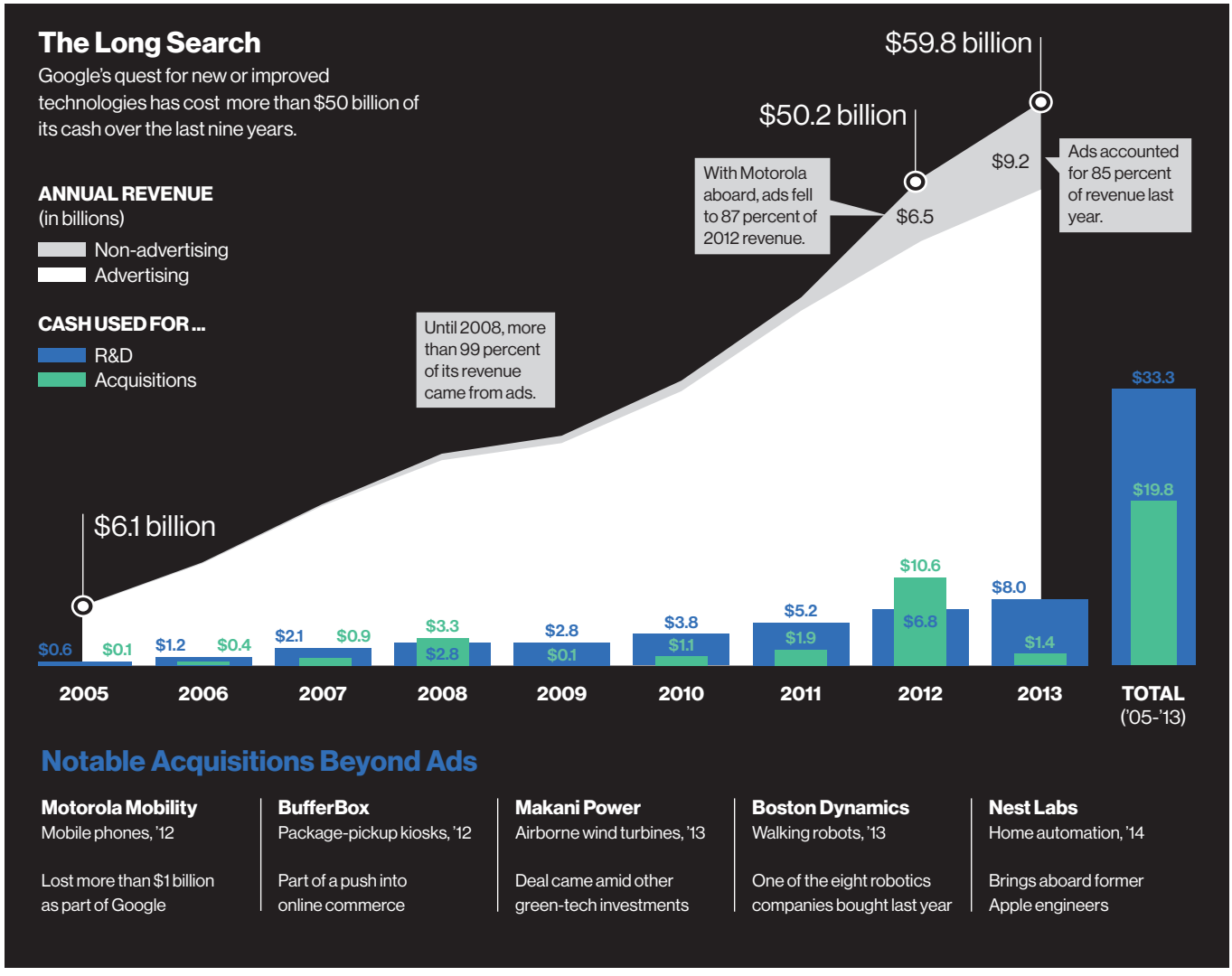
Google's problem is straightforward: its culture is rooted in building software, giving it away, and improving it over time—all with little in the way of advertising or marketing. Selling stuff requires the opposite—persuading customers that the product for sale is finished and perfect in every way.

So why can't Google just accept the market's judgment of its strengths and weaknesses and stop wasting shareholders' money trying to expand the revenue base? Because even though there is every indication that Google's advertising business will keep growing for years to come, nothing guarantees that it will dominate forever. Something could come along and do to search ads what search ads did to TV and newspaper ads.

That is why Google still hopes to compete with the likes of Apple in consumer electronics. And it's not too late, especially with Google's $3.2 billion purchase of Nest Labs in January.

Of course, acquisitions are rarely magic bullets, as Google can attest. And look at the business Nest is in: it makes home thermostats and smoke alarms, which, to be kind, have been on the trailing edge of innovation. But that's what makes this purchase interesting. Nest has transformed these moribund categories with clever products that learn their users' preferences and feel like things you would buy in an Apple store, which in fact is one of the places they are sold. Even though Nest's thermostat costs $250, market analysts estimate that consumers have been buying more than 50,000 units a month.

CHART BY INFOGRAPHICS.COM. DATA FROM GOOGLE FILINGS. ACQUISITION COSTS ARE NET OF CASH ACQUIRED AND DIVESTITURE PROCEEDS AND EXCLUDE ACQUISITIONS MADE WITH STOCK.



↑ Google spends a lot on R&D—usually about 13 percent of its annual revenue.

What really made the Nest deal attractive, however, was the people. Nest's CEO and cofounder is Tony Fadell, the former Apple executive who was critical in that company's rebirth. He helped build and design the iPod, and then he helped conceive and build the iPhone. Fadell and cofounder Matt Rogers, who was also one of the early iPhone engineers, have hired roughly 100 of Apple's top engineers and marketers, according to public profile data on LinkedIn. They made Nest one of the largest repositories of ex-Appleites in Silicon Valley.

Indeed, buying Nest could be Google cofounder Larry Page's most important deal since he became CEO in 2011. Motorola didn't bring much expertise in design or marketing, whereas Fadell spent a decade working for Steve Jobs, giving him insights he used to turn Nest into an overnight success. Now he reports to Page, and Google might finally produce a new kind of innovation. —*Fred Vogelstein*

20

Second Sight

Makes an artificial retina for people with certain kinds of blindness.

74: number of blind people who have gotten the Argus II implant

21

SpaceX

Where would NASA be without it?

14: launches scheduled for this year—one more than it had from 2006 through 2013

22

Kickstarter

Keeping crowdfunding pure, it won't let donors get equity in startups.

$962 million: money pledged on the site for 55,000 projects

23

Hanergy Holding Group

Chinese energy company is snapping up advanced solar technologies at fire-sale prices.

$1.2 billion: onetime value of Miasole, a solar company that Hanergy bought for $30 million

Third Rock Ventures

These VCs don't wait for biotech startups to come to them. They create companies themselves.

8

THE PATH TO GREATNESS IN biotechnology runs through a vale of tears. Mark Levin wants to remember that.

So once every few months the 40-person staff of Levin's venture capital firm, Third Rock Ventures, gathers silently to listen. Their speaker last September was Peter Frates, a 29-year-old former captain of the Boston College baseball team. In a voice slurred by spreading paralysis, Frates recalled how his doctors told him, "You have amyotrophic lateral sclerosis" and then sent him home. There was nothing to do.

Inventing a treatment for ALS is immensely challenging. Most drugs fail. Even so, Third Rock intends to try. Since 2006, Levin and cofounders Kevin Starr and Bob Tepper have backed 32 companies that have 25 products in human trials. Its newest venture, Voyager Therapeutics, is typically ambitious: it will have $45 million to try to develop a gene therapy for nervous-system disorders such as ALS. Levin himself will be the CEO.

"The big difference is they go in on their own, and they go in big," says Amber Salzman, a biotech executive whose son was born with adrenoleukodystrophy. That heartbreaking inherited disease is now in the sights of Bluebird Bio, a gene therapy company that went public last June—one of three IPOs for Third Rock startups last year.

Levin grew up in St. Louis, son of a small-time entrepreneur who sold shoes. He bought a doughnut shop and worked in process engineering at Miller Brewing before making a name as a dealmaker in California's early biotech scene. "That was a crazy time, when anything was possible," he says.

A similar spirit pervades Third Rock's warren of offices in a Boston brownstone. A gumball machine at the entrance declares it an entrepreneurial space. Slogans on the wall say "Do the right thing" and "Make them raving fans." Levin, immensely rich from companies he's sold, comes to the office in outrageous jewelry and neon sneakers.

Third Rock has a unique approach to sizing up emerging technologies. The firm cultivates a long to-do list of ideas, like one for "personalized vaccines" and one for a "molecular stethoscope." It then spends three or four years studying the science and the markets, and seducing the world's leading experts to sign on.

"Some people can spot what is going to be extraordinary in five or 10 years," says Gregory Verdine, a chemistry professor who was lured out of a tenured position at Harvard to run another Third Rock company, Warp Drive Bio. "And then there are those who can imagine it and actually build it."

Verdine puts Levin in the category of great leaders, citing his ability to attract the best people to his causes. He is "an extraordinarily empathetic person," Verdine says, "who wants to leave his mark on biotech."

—Antonio Regalado

ILLUSTRATION BY QUICKHONEY; BIOTECH DATA FROM PHRMA, ERNST & YOUNG

Mark Levin, 63
Partner, Third Rock Ventures
Boston

"We're always listening to the experts, watching them, hearing them talk about the genetics, the biology, or what's happening in chemistry. You can just feel it if we are on the edge of something. It's a visceral experience." —Mark Levin

Capital raised by Third Rock

$1.3 billion

Companies it has funded

32

Typical investment per company

$30 million

Time it generally takes for companies to bring a new drug to market

10–15 years

Percentage of U.S. biotech companies with one year of cash left

33

24

Siemens

Its advances are bringing down the cost of offshore wind power.

13,100: number of its wind turbines installed worldwide

25

1366 Technologies

See story on p. 38.

26

Uber

Disrupting the taxi business.

69: number of cities worldwide in which people can use Uber's app to summon rides

27

Evernote

Its tools for managing information overload get ever more useful.

$45: cost of an annual subscription to Evernote Premium

28

Baidu

Chinese Web-search leader is expanding globally, heightening competition with Google.

8 miles: distance from Baidu's new Silicon Valley research lab to Google headquarters

Cree

By making a cheaper LED lightbulb, the newcomer to the industry hopes to dominate the market for energy-efficient lighting alternatives.

13

Opportunity: Driven in part by new government regulations on energy efficiency, LED lighting is increasingly replacing both incandescent and fluorescent lighting in everything from desk lamps to streetlights. LED lighting, which uses semiconductors to produce the illumination, offers various benefits: it's more energy efficient, a bulb lasts many years, and it's dimmable. What's more, thanks to advances in the technology over the last decade, LEDs produce light of reasonably good quality. But many consumers and businesses have been reluctant to switch over to the new technology. That's partly because initial products were ungainly and because LED lights are more expensive than incandescent bulbs, a technology that dates back to Thomas Edison.

Innovation: Cree started out as a supplier of components to other LED makers. Two years ago, however, unsatisfied with the quality of LED-based bulbs made by those established manufacturers, engineers at Cree resolved to design and make their own. Last year, Cree released a consumer product with the familiar shape and light quality of an old-style filament bulb, priced at under $14 for the equivalent of a 60-watt bulb; LED bulbs had been selling for more than twice that just a few years earlier. The company has begun selling its bulbs at Home Depot.

Cree's LED bulb competes directly with ones from lighting giants such as General Electric, Philips, and Osram Sylvania. But Cree now sells about $500 million worth of LED lighting annually and has nearly 10 percent of the market in North America, according to the Carnotensis Consultancy.

Inside each bulb is the source of Cree's technology advantage: a series of LEDs, each about half the size of a typical pencil eraser. Cree makes them on silicon carbide wafers, allowing the company to produce more light from an LED chip than competitors that use sapphire substrates. But price, ultimately, is what drives consumers. And Cree predicts it will be able to match traditional lighting on price in the not-very-distant future.

—Martin LaMonica

FREDRIK BRODEN

29

Github

This site for sharing computer code is part productivity tool, part social network.

10.7 million: number of "repositories" of shared software on the site

30

Xiaomi

See story on p. 40.

31

Oculus VR

Its soon-to-be released virtual-reality headset should help the technology live up to its potential.

21: age of founder Palmer Luckey

32

Qihoo 360 Technology

Leading Chinese antivirus company, moving into Web search.

$12 billion: Qihoo's market capitalization

33

Monsanto

Continues to dominate development and sales of genetically modified crops.

$1.53 billion: R&D spending in 2013

1366 Technologies

The company has managed the nearly impossible for a solar startup over the last few years: it is still in business.

25

THE FIRST THING TO KNOW about 1366 Technologies is that it has survived. Over the last three years, a long list of solar-power manufacturers have gone out of business, including BP Solar and startups Abound Solar and Solyndra. Not only has 1366 managed to remain afloat through this period, but it has prospered, in a deliberate and methodical way.

Last year the company opened a demonstration-scale factory to produce silicon wafers, a critical component in the most common type of solar cells. If all goes well, early next year it will break ground on a much larger factory financed in part by a federal loan guarantee it secured in June 2011, a few months before Solyndra infamously went bankrupt.

CEO Frank van Mierlo is confident that the failures of solar manufacturing are yesterday's story. He beams with pride as he shows a visitor around the company's factory in suburban Boston. Although it's modest compared with a commercial plant, the many pieces of equipment underscore the investment required to make solar cells.

One room, though, is strictly off-limits to outsiders. In it are two custom-built furnaces that produce thin six-inch-square wafers directly from molten silicon. The final wafers are identical to those made in today's conventional solar factories, where they are cut from ingots. But 1366's machines simplify the traditional manufacturing process into one step, slashing costs by more than half. That's important, since silicon wafers account for about 40 percent of the cost of today's solar panels, and manufacturers are hungry for even tiny cost reductions.

The heart of the technology is a dishwasher-size machine that freezes the molten silicon into wafers. Chief technology officer Emanuel Sachs, a former professor at MIT, demonstrated the concept with a bath of liquid tin. He then adapted the technology to small silicon wafers, and finally to wafers of industry-standard size. The company's machine now turns out more than 1,000 wafers a day.

Sachs also invented the technology behind Evergreen Solar, which went bankrupt in August 2011. Unlike Evergreen, though, 1366 chose to supply components for solar panels to other manufacturers, rather than trying to sell completed panels itself. This reduced the business risk of getting a new technology accepted and made it less expensive to scale up the manufacturing process.

By the end of next year, 1366 intends to have 50 machines at its planned $100 million factory, producing enough wafers for 250 megawatts of solar power. By then, analysts estimate, the market for solar will be gigawatts bigger than it is today. And the prospects for solar power could be brightening. *—Martin LaMonica*

FREDRIK BRODEN

34

Aquion Energy
Just finished a production line to make its low-cost battery for storing electricity off the grid.

$100 million+: capital raised

35

IBM
Its Watson system could deliver more answers from big data.

$1 billion: new investment IBM plans for Watson-related services

36

Jawbone
Making fitness tracking technology mainstream.

28: countries where the Up fitness band is sold

37

Medtronic
Continues to shrink life-saving implantable medical devices.

2 grams: weight of the world's smallest pacemaker

Xiaomi

This Chinese startup could outmaneuver big companies in the coming smartphone boom in developing countries.

30

STEVE JOBS JOLTED the mobile-phone business by introducing a device that everyone had to copy. Now his unabashed admirer Jun Lei is shaking up the enormous Chinese market with smartphones that cost much less than comparable devices.

Lei is founder and CEO of Xiaomi, which is just four years old but already one of the top six smartphone vendors in China. It entered the business in 2010 by releasing a custom Android operating system, known as MIUI (pronounced "me UI"), whose interface looked a lot like the iPhone's. It was hugely popular among enthusiasts who love to modify a phone's functions. A year later, Xiaomi began selling a series of phones that had high-end specs but sold for roughly half of what rival devices were going for in China.

One reason the prices are so low is that Xiaomi (pronounced "zho-me") sells at or near cost and makes its money when customers pay for its cloud-based services, such as messaging and data backup. The company is also skillful at timing its sales. It presells a very limited number of devices, which invariably sell out, attracting more interest. By the time the later buyers get their devices, manufacturing costs have declined significantly for Xiaomi.

Lei has cultivated a Jobs-like image, all the way down to his personal wardrobe and product announcements. His fans call him "Leibs" (a combination of Lei and Jobs), though his detractors also use the term in mockery. Regardless, his company is getting itself in position to sell a big chunk of the billion Android phones expected to flood the developing world in the next few years as prices keep falling. *—Xinyu Guan*

ILLUSTRATION BY QUICKHONEY; XIAOMI DATA FROM CANALYS; XIAOMI

Jun Lei, 44
Chairman and CEO, Xiaomi
Beijing, China

"Even a pig can fly if it sits in the right spot during a whirlwind."

— Jun Lei

Increase in smartphones sold in China in the third quarter of 2013, making it both the world's biggest and fastest-growing market

64%

Growth in Xiaomi's smartphone sales in 2013

160%

Year of Xiaomi's founding

2010

Xiaomi's 2013 revenue

$5.2 billion

Valuation in Xiaomi's last round of funding

$10 billion

38

Valve

A rising force in video games with its open-source console and online game distribution.

65 million: number of people using Valve's game-distribution network

39

Genomics England

Will run the U.K.'s project to make DNA sequencing part of the country's health-care system.

100,000: number of genomes the company hopes to sequence in five years

40

D-Wave Systems

It's not clear whether it has invented quantum computers. But its machines solve certain problems remarkably well.

30 minutes: time it took in one study for a conventional computer to solve a problem that D-Wave's machine handled in less than half a second

41

Siluria Technologies

See the story at right.

Siluria Technologies

If it can convert natural gas to transportation fuels and commodity chemicals, it could reduce our dependence on oil.

41

Opportunity: Making gasoline from natural gas rather than oil could cut its cost in half. Such a technology could also help make plastics far cheaper. While oil costs around $100 a barrel, natural gas sells in the U.S. for the equivalent of about $20 a barrel and is likely to remain much cheaper than oil for some time: it is estimated to be between two and six times more abundant than oil, and technologies like hydrofracking have led to a surge of production from unconventional sources like the Marcellus Shale in the eastern United States. Equally important, natural gas is more evenly distributed around the world than petroleum. The United States has ample supplies thanks to shale deposits, but so do China, many parts of Europe and South America, Australia, and South Africa. Making gasoline and commodity chemicals from natural gas rather than petroleum could help free the rest of the world from the political and economic stranglehold of the large oil-exporting nations.

Innovation: The goal of Siluria, a Silicon Valley startup fueled with $63.5 million in venture funding, is both audacious and simple: create a process that efficiently uses natural gas, rather than petroleum, to make ethylene and gasoline. The challenge is the chemistry. It's possible to use catalysts to make these products out of methane (the main ingredient in natural gas), but an efficient industrial process has eluded chemical engineers for decades.

Siluria thinks it can succeed where others have failed, not because it understands the chemistry better but because it has ways to rapidly make and screen potential catalysts. The company built an automated system that can quickly synthesize hundreds of different catalysts at a time and then test how well they convert methane into ethylene.

It works by varying both what catalysts are made of and their microscopic structure. Making a catalyst in, say, the shape of a nanowire changes the way it interacts with methane, and this can transform a useless combination of elements into an effective one.

Siluria says the catalysts produced at its pilot plant in Menlo Park, California, have performed well enough to justify building two larger demonstration plants—one across San Francisco Bay in Hayward that will make gasoline, and one in Houston that will make ethylene. The company hopes to prove that the technology will work at a commercial scale and can be plugged into existing refineries and chemical plants.

Siluria can't tell you exactly how it's solved the problem that stymied chemists for decades—if indeed it has. Because of the nature of its throw-everything-at-the-wall approach, it doesn't know precisely how its new catalysts work. All it knows is that the process appears to. *—Kevin Bullis*

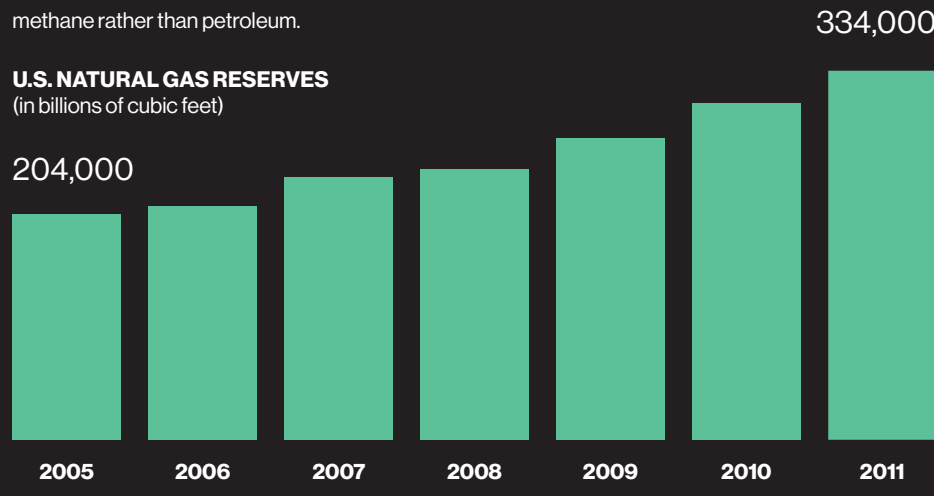
CHART BY INFOGRAPHICS.COM. DATA FROM EIA. IHS. PLATTS GLOBAL PETROCHEMICAL INDEX

Siluria wants to take advantage of the large increase in supplies of natural gas.

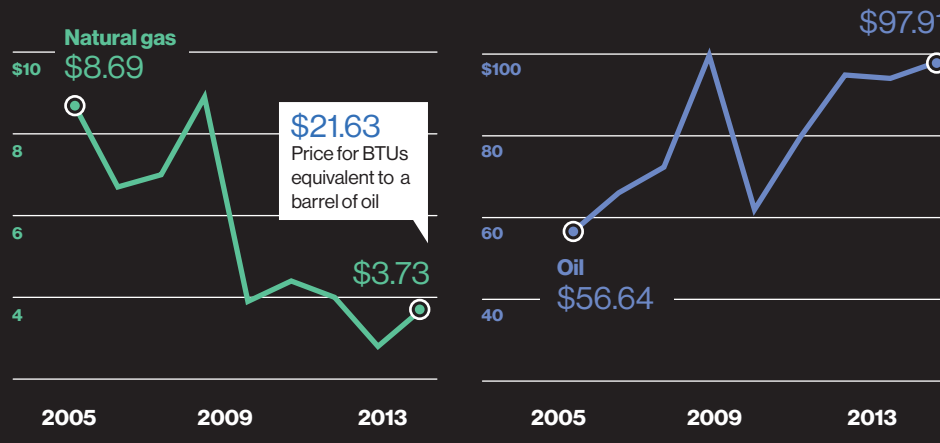
Making Oil Obsolete

The abundance of natural gas means it could be attractive to make fuels and chemicals out of methane rather than petroleum.

U.S. NATURAL GAS RESERVES
(in billions of cubic feet)



U.S. NATURAL GAS PRICE VERSUS OIL
(dollars per million BTUs; dollars per barrel)



CHEMICAL REACTION OF METHANE TO ETHYLENE

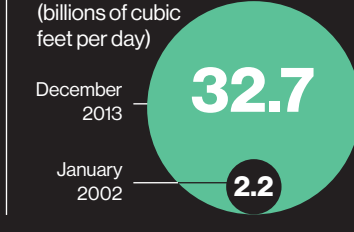
$$2CH_4 + O_2 \rightarrow C_2H_4 + 2H_2O$$

2 Methane · Oxygen · Ethylene · 2 Water

WORLD ETHYLENE MARKET

$150 billion

U.S. SHALE GAS PRODUCTION
(billions of cubic feet per day)



42

Kaiima Bio-Agritech

Developing a novel non-GMO way to breed crops with improved yields.

$65 million: investment raised in recent round

43

Datawind

Began as a project to spread cheap tablets to students in India; now selling devices everywhere.

$38: price of its cheapest tablet

44

Freescale Semiconductor

Making tiny computers for the Internet of things.

2 square millimeters: size of a Freescale chip that has a processor, memory, and other functions

45

Upworthy

See the story at right.

46

LG

Korean electronics giant's recent innovations include a smartphone with a flexible, curved screen.

30 percent: growth in LG's mobile phone business in 2013

Upworthy

45

Upworthy is one of the fastest-growing websites ever, despite producing only minimal original material. Instead, Upworthy highlights videos that people have posted online about gay marriage, health care reform, racial prejudice, gender equality, and other subjects that interest the site's liberal curators. The founders—Eli Pariser, who had led the left-wing political group MoveOn, and Peter Koechley, former managing editor of the satirical publication the *Onion*—started the site to help progressive-friendly content spread virally online, even if that means coöpting some sensational tactics from sites that propagate videos of cute cats. They spoke to *MIT Technology Review*'s deputy editor, Brian Bergstein.

Were you surprised at how quickly Upworthy got this big?
Pariser: We were blown away. We honestly never would have dreamed that the site would be as big as it is.

Koechley: A lot of people thought it was unlikely that there were 50 or 60 or 70 million people out there who wanted to watch videos about meaningful social issues.

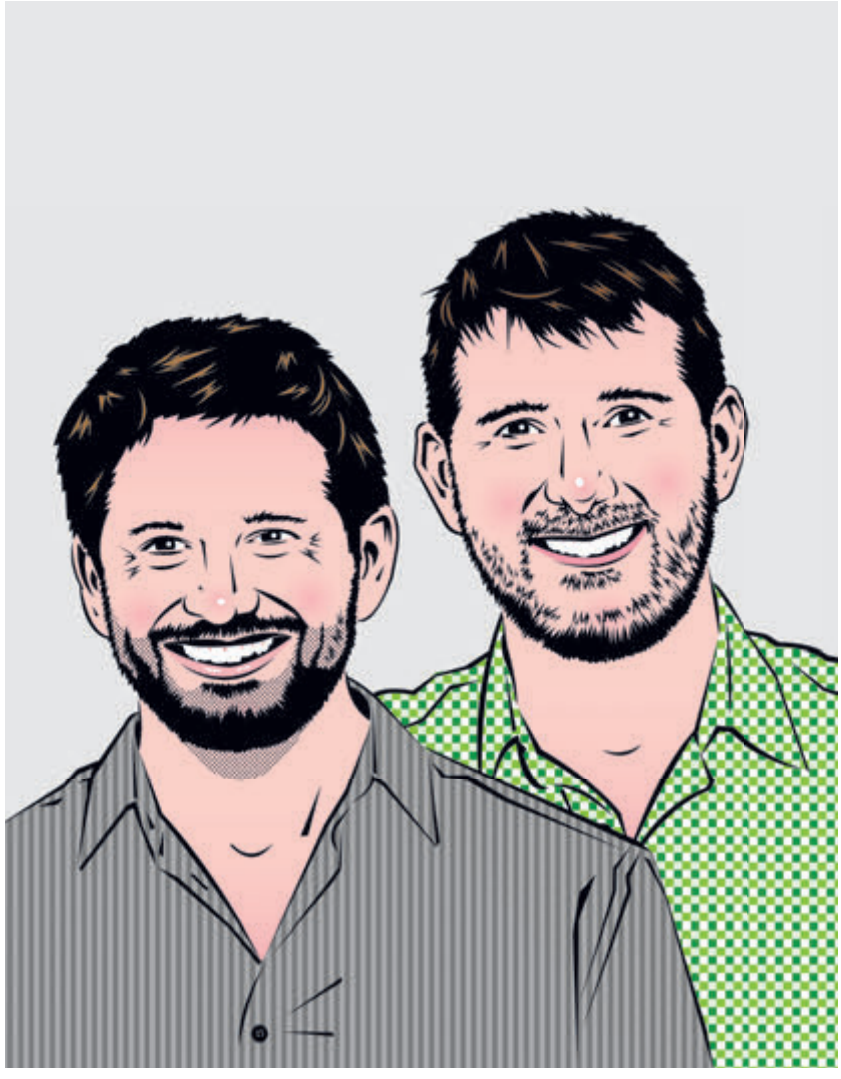
Describe Upworthy's system for making things go viral.
Pariser: There are hundreds of millions, if not billions, of videos posted every month, and our curators are looking for the several hundred that are very meaningful about some important topic and very, very compelling. We have various tools that our curators use, but ultimately it comes down to human judgment and their ability to find videos or charts or graphics that just blow them away.

Then they write headlines that have become an Upworthy signature. Your headlines are filled with superlatives—"the biggest," "the worst," "the most horrifying"—and tell readers that clicking the link will change their lives.
Pariser: Generally [the curators] write 25 or so headlines and then pick four to try out. And then sometimes they'll take a couple rounds of that. We think of it kind of like a comedian playing Duluth before you go to New York, working out the material and what people are laughing at.

Koechley: Headlines are a way to get somebody to watch a seven-minute video about depression or a 12-minute video about climate change. If you said "This is a 12-minute video about climate change," you just know that people won't click through. But if you actually bring out the stuff that speaks to their curiosity and their interest, you can connect people with ideas that they really love and enjoy.

You'll have to vary the tone if you want to keep standing out, though. Upworthy-style headlines are everywhere on the Web now.
Koechley: Totally. The number of new directions and formats and ideas that we're testing every day are legion.

QUICKHONEY



↑ Peter Koechley, 33
co-CEO, Upworthy
New York

↑ Eli Pariser, 33
co-CEO, Upworthy
New York

There have been hardly any ads on the site. How will you make money?
Pariser: We've mostly been focused on building our community so far. We're testing a number of revenue options now, and we're liking the underwriting model, where a foundation or similar group funds our editorial work in a specific topic.

Given that Eli wrote a book called *The Filter Bubble*, which decries how the Internet often limits people to information they agree with, it's disappointing that Upworthy repeatedly covers the same topics and doesn't seem to challenge liberal assumptions. You guys are playing it safe.
Koechley: I think the first problem we were trying to solve is: how can we go from people spending zero minutes a day thinking about important societal issues to spending 10 minutes, or 20 minutes, or five minutes? That said, one of the things we're planning for this year is we're choosing topics that we haven't gone all that deeply into. So we have a partnership with the Gates Foundation to go a lot deeper on global health and poverty.

We've now built a platform that is going to allow us to take on lot of really interesting [opportunities]. Challenging the audience to think in different ways or challenging their currently held beliefs is certainly one of those that we think is interesting.

"If you said 'This is a 12-minute video about climate change,' you just know that people won't click through. But if you actually bring out the stuff that speaks to their curiosity and their interest, you can connect people with ideas that they really love and enjoy." —Peter Koechley

47

Expect Labs

Its anticipatory software listens to your conversations so it can suggest relevant information.

8: number of people who can participate in a conversation through the company's MindMeld app

48

AngelList

Influential service acts as a matchmaker for early-stage investors and startups.

$1 billion: amount startups have raised through the site

49

Arcadia Biosciences

Tests crops designed to use less fertilizer and water or tolerate more salt.

50 percent: amount of nitrogen fertilizer needed by Arcadia's rice, compared with conventional strains

50

Ripple Labs

See the story at right.

Ripple Labs

A startup invented its own digital currency for exchanging money across borders.

50

IT'S A MONEYMAKING SCHEME a child might suggest: get rich by inventing a new form of money. All the same, Chris Larsen, CEO and founder of Ripple Labs, is getting other people to play along with him. And they aren't just Silicon Valley investors. People are using Ripple's digital cash to exchange traditional paper currencies.

Ripple's currency is modeled on the digital cash Bitcoin, which has boomed and sometimes busted in value over recent years (see chart on page 18), and both use similar cryptography to prevent fraud. But while Bitcoin is designed to be used like regular currency to buy things, Ripple's cash, known as XRP, is intended to make many foreign exchange transfers faster and less expensive.

Traditionally, a person who has Burmese kyats, for example, and needs to send money to someone in U.S. dollars has had to wait days for the transaction to clear, incurring sizable fees in the process. That's because international money transfer systems rely on centralized, decades-old systems to verify that payments are valid. But banks—or new, low-cost startup services—could use Ripple's technology to sidestep those systems. They would convert the payer's kyats into XRPs and then use the Ripple protocol to automatically find a partner willing to convert those XRPs into dollars, completing the deal almost instantly. A financial company might choose to hold a stash of XRPs of its own to make such transfers easier.

Larsen hopes this technology will stimulate international commerce and make it cheaper for expatriates to send money back to their families in poor countries. (The World Bank estimates that in 2012, almost 12 percent of the $60 billion in such remittances to African countries was swallowed by transaction fees.) Indeed, Ripple reports that transfers from Europe to China already make up a significant portion of the roughly $20 million processed using its technology every month.

The algorithms underlying Ripple's technology dictate that there will be no more than 100 billion XRPs to go around. Though the company is giving away many of them to get the system off the ground, it has allocated one-fourth of the hoard to itself and is relying on the XRP's increasing value as its only source of income. Between the freebies and the ones Ripple has sold to companies and investors who believe the currency will gain value, there are 7.5 billion XRPs in circulation. That's enough to make Ripple Labs' cash flow positive—and to show that inventing and selling your own currency really can work. —*Tom Simonite*

FREDRIK BRODEN

An Artificial Hand with Real Feeling

A new nerve interface gives a sense of touch to a prosthetic limb.

Story:
David Talbot

Photographs:
Ryan Donnell

Igor Spetic lost his hand in a workplace accident. Now he's one of the first people ever to regain realistic finger sensations thanks to nerve interfaces (facing page) implanted in the arm.

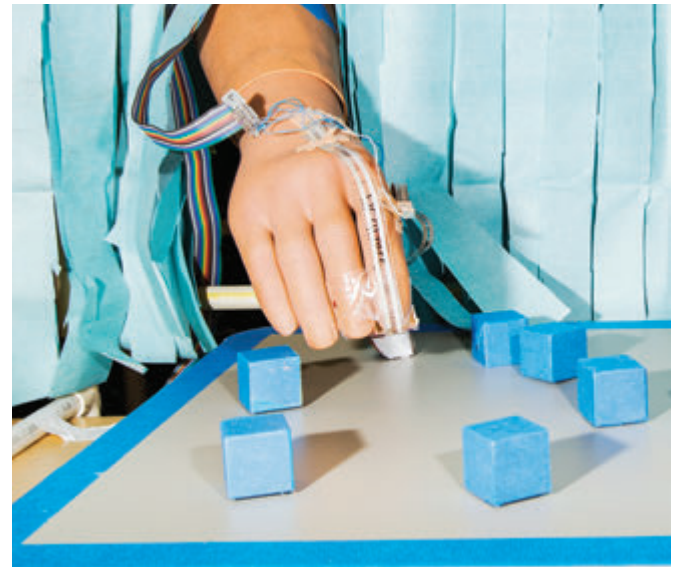
IGOR SPETIC'S HAND WAS IN A FIST WHEN it was severed by a forging hammer three years ago as he made an aluminum jet part at his job. For months afterward, he felt a phantom limb still clenched and throbbing with pain. "Some days it felt just like it did when it got injured," he recalls.

He soon got a prosthesis. But for amputees like Spetic, these are more tools than limbs. Because the prosthetics can't convey sensations, people wearing them can't feel when they have dropped or crushed something.

Now Spetic, 48, is getting some of his sensation back through electrodes that have been wired to residual nerves in his arm. Spetic is one of two people in an early trial that takes him from his home in Madison, Ohio, to the Cleveland Veterans Affairs Medical Center. In a basement lab, his prosthetic hand is rigged with force sensors that are plugged into 20 wires protruding from his upper right arm. These lead to three surgically implanted interfaces, seven millimeters long, with as many as eight electrodes apiece encased in a polymer, that surround three major nerves in Spetic's forearm.

On a table, a nondescript white box of custom electronics does a crucial job: translating information from the sensors on Spetic's prosthesis into a series of electrical pulses that the interfaces can translate into sensations. This technology "is 20 years in the making," says the trial's leader, Dustin Tyler, a professor of biomedical engineering at Case Western Reserve University and an expert in neural interfaces.

As of February, the implants had been in place and performing well in tests for more than a year and a half. Tyler's group, drawing on years of neuroscience research on the signaling mechanisms that underlie sensation, has developed a library of patterns of electrical pulses to send to the arm nerves, varied in strength and timing. Spetic says that these different stimulus patterns produce distinct and realistic



Facing page: When the sensory interface is disconnected, Spetic has trouble picking up cherries. He crushes them 23 percent of the time when he's allowed to watch his efforts, and 57 percent of the time when he can't watch.

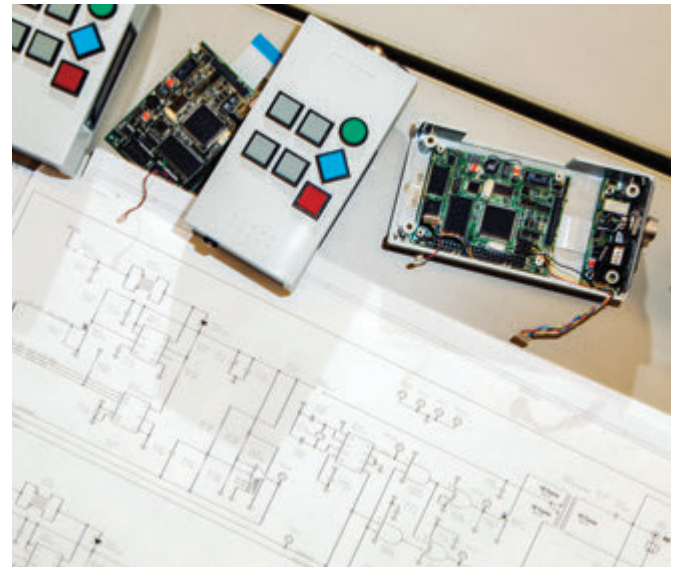
Top: To evaluate his sensory feedback, he picks up blocks held to the table with magnets. Bottom: With sensation restored, he can pick up cherries and remove stems 93 percent of the time without crushing, even blindfolded.

feelings in 20 spots on his prosthetic hand and fingers. The sensations include pressing on a ball bearing, pressing on the tip of a pen, brushing against a cotton ball, and touching sandpaper, he says. A surprising side effect: on the first day of tests, Spetic says, his phantom fist felt open, and after several months the phantom pain was "95 percent gone."

On this day, Spetic faces a simple challenge: seeing whether he can feel a foam block. He dons a blindfold and noise-canceling headphones (to make sure he's relying only on his sense of touch), and then a postdoc holds the block inside his wide-open prosthetic hand and taps him on the shoulder. Spetic closes his prosthesis—a task made possible by existing commercial interfaces to residual arm muscles—and reports the moment he touches the block: success.

While the results are promising, research that involves surgical implants is time-consuming. Completing the pilot study, refining stimulation methods, and launching full clinical trials is likely to take 10 years. Tyler is also finishing development of an implantable electronic device to deliver stimuli "so this is not just on a bench in a lab, but gets into the home eventually," he says. And he is working with manufacturers of prostheses to integrate force sensors and force processing technology directly into future versions of the devices.

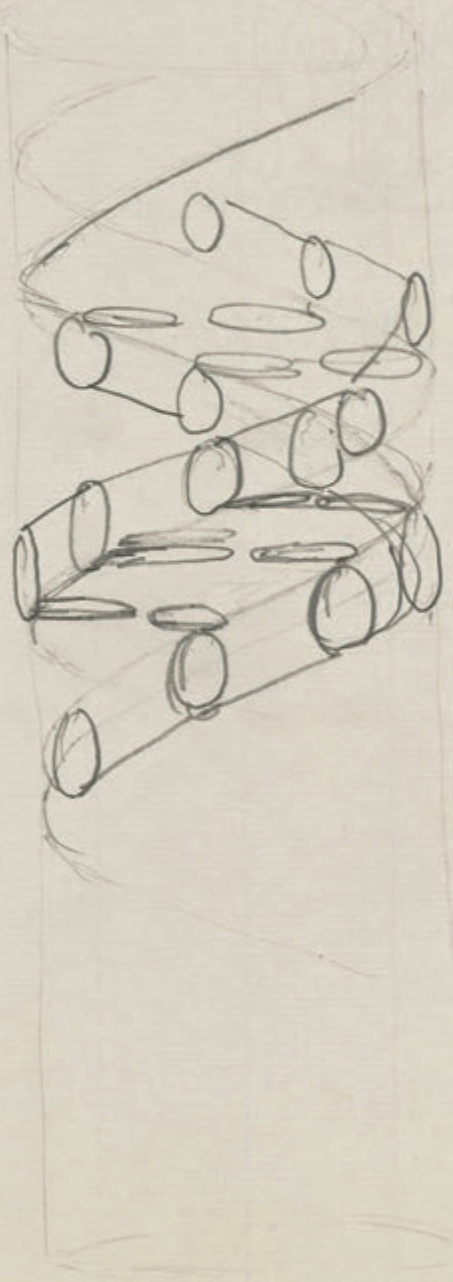
When the tests are over and the equipment is disconnected, Spetic's sensory visitation with his lost hand abruptly ends. He says he's "blessed to know these people and be a part of this." But he can't help thinking wistfully about what the future might bring. "It would be nice to know I can pick up an object without having to look at it, or I can hold my wife's hand and walk down the street, knowing I have a hold of her," he says, as he puts on his coat and starts back home. "Maybe all of this will help the next person." T



Facing page: A standard prosthetic hand is rigged with force sensors for lab trials.

Top: Control boxes deliver signals to electrodes surrounding nerves in Spetic's arm, producing sensations of touch.

Bottom: This device might eventually be implanted in his arm, replacing lab equipment to deliver signals. Force sensors and processing technology could be integrated into future prosthetic devices.



MIT TECHNOLOGY REVIEW
VOL. 117 | NO. 2

A sketch made by Francis Crick in 1953 shows his first impression of the DNA molecule.

COURTESY OF WELLCOME LIBRARY, LONDON

Genome Surgery

Precise and easy ways to rewrite human genes could finally provide the tools that researchers need to understand and cure some of our most deadly genetic diseases.

By Susan Young

OVER THE LAST DECADE, AS DNA-SEQUENCING TECHNOLOGY has grown ever faster and cheaper, our understanding of the human genome has increased accordingly. Yet scientists have until recently remained largely ham-fisted when they try to directly modify genes in a living cell. Take sickle-cell anemia, for example. A debilitating and often deadly disease, it is caused by a mutation in just one of a patient's three billion DNA base pairs. Even though this genetic error is simple and well studied, medical researchers are helpless to correct it and halt its devastating effects.

Now there is hope in the form of new genome-engineering tools, particularly one called CRISPR. This technology could allow researchers to perform microsurgery on genes, precisely and easily changing a DNA sequence at exact locations on a chromosome. Along with a technique called TALENs, invented several years ago, and a slightly older predecessor based on molecules called zinc finger nucleases, CRISPR could make gene therapies more broadly applicable, providing remedies for simple genetic disorders like sickle-cell anemia and eventually even leading to cures for more complex diseases involving multiple genes. Most conventional gene therapies crudely place new genetic material at a random location in the cell and can only add a gene. In contrast, CRISPR and the other new tools also give scientists a precise way to delete and edit specific bits of DNA—even by changing a single base pair. This means they can rewrite the human genome at will.

It is likely to be at least several years before such efforts can be developed into human therapeutics, but a growing number of academic researchers have seen some preliminary success with experiments involving sickle-cell anemia, HIV, and cystic fibrosis (see table on page 58). One is Gang Bao, a bioengineering researcher at the Georgia Institute of Technology, who has already used CRISPR to correct the sickle-cell mutation in human cells grown in a dish. Bao and his team started the work in 2008 using zinc finger nucleases. When TALENs came out, his group switched quickly, says Bao, and then it began using CRISPR when that tool became available. While he has ambitions to eventually work on a variety of diseases, Bao says it makes sense to start with sickle-cell anemia. "If we pick a disease to treat using genome editing, we should start with something relatively simple," he says. "A disease caused by a single mutation, in a single gene, that involves only a single cell type."

Bao has an idea of how such a treatment would work. Currently, physicians are able to cure a small percentage of sickle-cell patients by finding a human donor whose bone marrow is an immunological match; surgeons can then replace some of the patient's bone marrow stem cells with donated ones. But such donors must be precisely matched with the patient, and even then, immune rejection—a potentially deadly problem—is a serious risk. Bao's cure would avoid all this. After harvesting blood cell precursors called hematopoietic stem cells from the bone marrow of a sickle-cell patient, scientists would use CRISPR to correct the defective gene. Then the gene-corrected stem cells would be returned to the patient, producing healthy red blood cells to replace the sickle cells. "Even if we can replace 50 percent, a patient will feel much better," says Bao. "If we replace 70 percent, the patient will be cured."

Though genome editing with CRISPR is just a little over a year old, it is already reinventing genetic research. In particular, it gives scientists the ability to quickly and simultaneously make multiple genetic changes to a cell. Many human illnesses, including heart disease, diabetes, and assorted neurological conditions, are affected by numerous variants in both disease genes and normal genes. Teasing out this complexity with animal models has been a slow and tedious process. "For many questions in biology, we want to know how different genes interact, and for this we need to introduce mutations into multiple genes," says Rudolf Jaenisch, a biologist at the Whitehead Institute in Cambridge Massachusetts. But, says Jaenisch, using conventional tools to create a mouse with a single mutation can take up to a year. If a scientist wants an animal with multiple mutations, the genetic changes must be made sequentially, and the timeline for one experiment can extend into years. In contrast, Jaenisch and his colleagues, including MIT researcher Feng Zhang (a 2013 member of our list of 35 innovators under 35), reported last spring that CRISPR had allowed them to create a strain of mice with multiple mutations in three weeks.

Because a CRISPR system can easily be designed to target any specific gene, the technology is allowing researchers to do experiments that probe a large number of them. In December, teams led by Zhang and MIT researcher Eric Lander created libraries of CRISPRs, each of which targets a different human gene. These vast collections, which account for nearly all the human genes, have been made available to other researchers. The libraries promise to speed genome-wide studies on the genetics of cancer and many other human diseases.

In little more than a year, CRISPR has begun reinventing genetic research.

Editing Options

	1 Zinc finger nucleases	2 TALENs	3 CRISPR
What is it?	A protein consisting of a DNA-cutting enzyme and a DNA-grabbing region that can be tailored to recognize different genes.	Also a protein containing a DNA-cutting enzyme and a DNA-grabbing region that can be programmed to recognize different genes, but it is easier to design than zinc finger nucleases.	A DNA-cutting protein guided by an RNA molecule that is able to find the specific gene of interest.
Pros and cons	It was the first programmable genome-editing tool, but it relies on proteins that can be difficult to engineer for new gene targets. Potentially dangerous off-target cuts are also possible.	Though simpler and cheaper to design than zinc finger nucleases, TALEN proteins can still be difficult to produce and deliver. Off-target cuts are a problem.	This technique is affordable and easy to use, and it works for high-throughput, multi-gene experiments. Like the other tools, it can make off-target cuts.

Genome GPS

The biotechnology industry was born in 1973, when Herbert Boyer and Stanley Cohen inserted foreign DNA that they had manipulated in the lab into bacteria. Within a few years, Boyer had cofounded Genentech, and the company had begun using *E. coli* modified with a human gene to manufacture insulin for diabetics. In 1974, Jaenisch, then at the Salk Institute for Biological Studies in San Diego, created the first transgenic mouse by using viruses to spike the animal's genome with a bit of DNA from another species. In these and other early examples of genetic engineering, however, researchers were limited to techniques that inserted the foreign DNA into the cell at random. All they could do was hope for the best.

It took more than two decades before molecular biologists became adept at efficiently changing specific genes in animal genomes. Dana Carroll of the University of Utah recognized that zinc finger nucleases, engineered proteins reported by colleagues at Johns Hopkins University in 1996, could be used as a programmable gene-targeting tool. One end of the protein can be designed to recognize a particular DNA sequence; the other end cuts DNA. When a cell then naturally repairs those cuts, it can patch its genome by copying from supplied foreign DNA. While the technology finally enabled scientists to confidently make changes where they want to on a chromosome, it's difficult to use. Every modification requires the researcher to engineer a new protein tailored to the targeted sequence—a difficult, time-consuming task that, because the proteins are finicky, doesn't always work.

TALENs, another significant advance in gene editing, came along in 2010. TALENs are also proteins that find and cut a desired DNA sequence—but tailoring them to new gene targets is much easier. While they represented a great improvement over zinc fingers, however, TALENs are large proteins that are cumbersome to work with and deliver into cells.

CRISPR changed everything. It replaces the DNA-targeting proteins with a short bit of RNA that homes in on desired genes. Unlike the complex proteins, RNA—which has nearly the same simple structure as DNA—can be made routinely in the lab; a technician can quickly synthesize the roughly 20-letter-long sequences the method requires. The system makes it easy for medical researchers to modify a genome by replacing, deleting, or adding DNA.

CRISPR stands for "clustered regularly interspaced short palindromic repeats"—clusters of brief DNA sequences that read similarly forward and backward, which are found in many types of bacteria. Scientists first observed the puzzling DNA segments in the 1980s but didn't understand for almost two decades that they are part of a bacterial defense system. When a virus attacks, bacteria can incorporate sequences of viral DNA into their own genetic material, sandwiching them between the repetitive segments. The next time the bacteria encounter that virus, they use the DNA in these clusters to make RNAs that recognize the matching viral sequences. A protein attached to one of these RNAs then cuts up the viral DNA.

In 2012, Emmanuelle Charpentier, a medical microbiologist who studies pathogens at the Helmholtz Centre for Infection Research, and Jennifer Doudna, a collaborator at the University of California, Berkeley, showed they could use a single RNA in conjunction with the cutting protein, an enzyme called Cas9, to slice any desired sequence of DNA in test tubes. It was still uncertain whether the method would work in animal cells, but in January 2013 came a dramatic breakthrough. Zhang and George Church, a Harvard Medical School geneticist, separately reported that the CRISPR/Cas9 system could be used for gene editing in the cells of animals, including humans.

Now a researcher who wants to go after a new gene need only synthesize the Cas9 protein and a bit of RNA that matches the sequences of the targeted region. The RNA then guides the enzyme to the DNA the researcher wants to cut. And because the same cutting protein is used regardless of the target, researchers can design experiments in which they change multiple genes in an organism simultaneously using Cas9 and multiple RNA guides. "It offers the potential to do experiments that in the past were very difficult or essentially not possible," says Doudna.

Complex Mysteries

MIT's Zhang, who is a member of the Broad Institute and the McGovern Brain Institute, is interested in the genetics behind mental illness. To try to understand these complex conditions, Zhang has helped develop multiple gene- and neuron-modifying tools, including TALENs and optogenetics, a technique that involves controlling neuron activity with laser light. When he first heard about CRISPR, in 2011, he began to engineer it for use in human cells. Now he's using CRISPR to help reveal the genetic secrets behind such devastating and poorly understood conditions as schizophrenia and autism.

The tool allows Zhang to begin systematically testing some of the DNA variants that have been linked to the illnesses. While much progress has been made over the last decade toward identifying genes that are common in people with these conditions, understanding how these genes relate to the symptoms is a daunting challenge. "What you learn from sequencing is only an observation," says Zhang: in order to understand whether a suspected gene is actually causing the condition, you have to introduce the specific mutation into healthy cells or organisms and see what goes wrong. If the mutated cell or organism has features that mimic the human disease, that's evidence implicating the gene.

Zhang can re-create, in both lab mice and cultured human cells, genetic variants found in people with autism and schizophrenia. "You can put a human mutation into the corresponding gene in a lab animal and then see: does that animal become less social or have a learning deficit?" he says. Then, he adds, you can study differences in the behavior and physiology of lab-cultured neurons grown from stem cells that have been modified with the same mutation. "With single-gene muta-

The Road to a Cure

	Sickle-cell anemia	HIV	Cystic fibrosis
Strategy	Correct the sickle-cell mutation in stem cells taken from a patient and then inject the cells back into the patient; alternatively, reactivate a suppressed fetal hemoglobin gene in the same cell type.	Prevent HIV from spreading to new immune cells in infected patients by altering genes the virus uses to enter cells in immune cell precursors; alternatively, destroy inactive HIV residing in the human genome by altering critical viral genes.	Correct cystic fibrosis mutations in the genomes of airway cells and other affected cell types.
Status	Correction strategy works in human cells in a petri dish; zinc finger nucleases, TALENs, and CRISPR have all been used successfully. Reactivation strategy using zinc finger nucleases has been demonstrated in human cells and mice.	Prevention strategy based on zinc finger nucleases is in human testing; TALEN and CRISPR versions have been shown in lab cells. The strategy to eliminate latent virus has also worked in cells, using zinc finger nucleases and CRISPR.	Zinc finger nucleases and TALENs have been shown to correct the cystic fibrosis gene in cultured airway cells; CRISPR can correct the gene in cultured organlike clumps made from human intestinal stem cells.

Perhaps scientists could rewrite normal genes so that humans could better fight infections.

tions, we will start to see aspects of the biological function that are involved in autism," he says.

Zhang is also using CRISPR to make multiple genetic changes at once. That becomes particularly important with complex diseases like autism and schizophrenia, which for the most part are not caused by the type of single DNA change behind sickle-cell anemia. Different patients are affected by different collections of mutations. Solving a puzzle of such immense complexity will require large, systematic studies on the effects of various genes and the way they interact. CRISPR makes such studies possible, says Zhang, and will be important in finding treatments for a variety of complex diseases. "We will understand more about pathways and disease mechanisms," he says. "This knowledge will inform all kinds of drug development."

Designer Babies

Late last year, Doudna, Zhang, Church, and two other pioneers of genome editing founded a startup that will develop novel treatments for human genetic diseases. In November the company, Editas Medicine, announced that it had raised $43 million in venture capital and said it plans to use genome-editing technologies against a broad range of illnesses (one of Editas Medicine's venture capital investors, Third Rock Ventures, is profiled on page 34).

The launch of Editas should benefit from a resurgence of interest in gene therapy thanks to years of technological improvements, including safer mechanisms for delivering treatment. "The landscape has changed for gene therapy," says Church. (There are still no gene therapies approved in the United States, though a number are in human trials.) But he says the therapies that Editas will develop will be fundamentally different from the older approaches that use a virus to insert a gene into cells.

"Making a change or a deletion is out of range for most of those simple viral methods," Church says. And deleting a bit of DNA, rather than adding a gene, may indeed be the key to treating many illnesses. Take Huntington's disease. The fatal brain condition arises from a buildup of a toxic protein in neurons. Adding a healthy copy of the gene to the cell would not affect that protein's poisonous activity: the original dysfunctional version must be rewritten. With the new genome-editing tools, says Church, rewriting the defective DNA may be possible: "You aren't limited to adding back something that is missing." And, he adds, "when you start realizing that the most common versions of genes are not necessarily the ideal versions, then you realize this is a much bigger field." Perhaps scientists could rewrite normal genes so that humans can better fight infectious diseases. They might even be able to shake up the molecular pathways involved in aging.

Church also predicts that if genome editing is used to cure childhood diseases, some scientists will be tempted to use it to engineer embryos during in vitro fertilization. Researchers have already shown that genome editing can rewrite DNA sequences in rat and mouse embryos, and in late January, researchers in China reported that they had created genetically modified monkeys using CRISPR. With such techniques, a person's genome might be edited before birth—or, if changes were made to the eggs or sperm-producing cells of a prospective parent, even before conception.

These possibilities raise ethical questions. But if researchers prove they can safely correct diseases by editing the genome, it's inevitable that some parents will also want to alter the genomes of healthy embryos. "If you can prevent mental retardation with gene therapy, presuming that that's permissible, then there's a whole spectrum of intellectual challenges that will be discussed," says Church.

Such discussions are likely to heat up as CRISPR becomes more widely used. For now, though, the technology is still evolving: while researchers like Bao, Church, and Zhang ultimately hope to cure some of our most intractable diseases, much of their time is still spent simply fine-tuning the tool and exploring its possibilities. But even in these early days, CRISPR has already transformed how these researchers think about manipulating the genome. They are ham-fisted no longer.

Susan Young is MIT Technology Review*'s biomedicine editor.*

MIT Technology Review

Digital Summit

MIT Technology Review subscribers **SAVE 10%.** Use code *TRSub* at registration.

Innovations and Ideas Fueling Our Connected World

Speakers include:

Rob Chandhok
Senior Vice President, Qualcomm Technologies; President, Qualcomm Interactive Platforms

Di-Ann Eisnor
VP Platform & Partnership
Waze

Anthony Goldbloom
Founder and CEO
Kaggle

Phil Libin
CEO
Evernote

Thad Starner
Professor, School of Interactive Computing
Georgia Institute of Technology

June 9-10, 2014 San Francisco, CA St. Regis Hotel

The MIT Technology Review Digital Summit examines tomorrow's digital technologies and explains their global impact on business and society. You'll get access to the innovative people and companies at the heart of the next wave of the digital revolution.

Featured topics include:

- The Internet of Things: Connected Cars, Homes, Commerce, Health, Cities
- The Disappearing Interface
- Digital Privacy

Questions? Please e-mail:
eventsreg@technologyreview.com

Partner:

CSAIL·IAP
INDUSTRY AFFILIATES PROGRAM

REGISTER BY APRIL 9 AND SAVE $600: technologyreview.com/DigitalSummit

Data and Decision Making

Big data, artificial intelligence, and analytics software are changing forever how businesses decide what to do.

CONTENTS

Read the full report online at technologyreview.com/business

MIGUEL MONTANER

The Big Question

The Power to Decide

What's the point of all that data, anyway? It's to make decisions.

● Back in 1956, an engineer and a mathematician, William Fair and Earl Isaac, pooled $800 to start a company. Their idea: a score to handicap whether a borrower would repay a loan.

It was all done with pen and paper. Income, gender, and occupation produced numbers that amounted to a prediction about a person's behavior. By the 1980s the three-digit scores were calculated on computers and instead took account of a person's actual credit history. Today, Fair Isaac Corp., or FICO, generates about 10 billion credit scores annually, calculating 50 times a year for many Americans.

This machinery hums in the background of our financial lives, so it's easy to forget that the choice of whether to lend used to be made by a bank manager who knew a man by his handshake. Fair and Isaac understood that all this could change, and that their company →

didn't merely sell numbers. "We sell a radically different way of making decisions that flies in the face of tradition," Fair once said.

This anecdote suggests a way of understanding the era of "big data"—terabytes of information from sensors or social networks, new computer architectures, and clever software. But even supercharged data needs a job to do, and that job is always about a decision.

In this business report, *MIT Technology Review* explores a big question: how are data and the analytical tools to manipulate it changing decision making today? On Nasdaq, trading bots exchange a billion shares a day. Online, advertisers bid on hundreds of thousands of keywords a minute, in deals greased by heuristic solutions and optimization models rather than two-martini lunches. The number of variables and the speed and volume of transactions are just too much for human decision makers.

10 billion
Credit scores generated each year

When there's a person in the loop, technology takes a softer approach. Think of recommendation engines on the Web that suggest products to buy or friends to catch up with. This works because Internet companies maintain statistical models of each of us, our likes and habits, and use them to decide what we see. In this report, we check in with LinkedIn, which maintains the world's largest database of résumés—more than 200 million of them. One of its newest offerings is University Pages, which crunches résumé data to offer students predictions about where they'll end up working depending on what college they go to.

These smart systems, and their impact, are prosaic next to what's planned. Take IBM. The company is pouring $1 billion into its Watson computer system, the one that answered questions correctly on the game show *Jeopardy!* IBM now imagines computers that can carry on intelligent phone calls with customers, or provide expert recommendations after digesting doctors' notes. IBM wants to provide "cognitive services"—computers that think, or seem to.

Andrew Jennings, chief analytics officer for FICO, says automating human decisions is only half the story. Credit scores had another major impact. They gave lenders a new way to measure the state of their portfolios—and to adjust them by balancing riskier loan recipients with safer ones. Now, as other industries get exposed to predictive data, their approach to business strategy is changing, too. In this report, we look at one technique that's spreading on the Web, called A/B testing. It's a simple tactic—put up two versions of a Web page and see which one performs better.

Until recently, such optimization was practiced only by the largest Internet companies. Now, nearly any website can do it. Jennings calls this phenomenon "systematic experimentation" and says it will be a feature of the smartest companies. They will have teams constantly probing the world, trying to learn its shifting rules and deciding on strategies to adapt. "Winners and losers in analytic battles will not be determined simply by which organization has access to more data or which organization has more money," Jennings has said.

Of course, there's danger in letting the data decide too much. In this report, Duncan Watts, a Microsoft sociologist specializing in social networks, outlines an approach to decision making that avoids the dangers of gut instinct as well as the pitfalls of slavishly obeying data. In short, Watts argues, businesses need to adopt the scientific method.

To do that, they have been hiring a highly trained breed of business skeptics called data scientists. These are the people who create the databases, build the models, reveal the trends, and, increasingly, author the products. And their influence is growing in business. This could be why data science has been called "the sexiest job of the 21st century." It's not because mathematics or spreadsheets are particularly attractive. It's because making decisions is powerful. —*Antonio Regalado*

Emerged Technologies

Seeking Edge, Websites Turn to Experiments

Optimization technology is reshaping publishers' decision-making process—and the Web itself.

● 1-800-Dentist is a small company facing a big decision. What picture on its Web home page will get the most people to fill out a form with their names and phone numbers?

At many Web publishers, such decisions can lead to impassioned arguments, fruitless debates, even hurt feelings. But 1-800-Dentist doesn't leave it to chance or opinion. Instead it runs an experiment. It launches two or more versions of a Web page, and then watches as users react. After thousands of people have visited, one version will have edged out the others with a statistically significant improvement in the number of sign-ups.

Such optimization testing is quickly spreading across the Web. And as companies gain access to tools that let them run their businesses like ongoing science experiments, it's changing not only how decisions get made but what the Web looks like. "There used to be a battle of opinions in our company," says Elliot Kharkats, the Web analytics and testing manager for 1-800-Dentist. "The designer would get upset. The boss would intervene. But we don't have a story like that anymore. No one is really committed to their version anymore, because testing proves over and over again that the smartest people in the room are just wrong."

41
Shades of blue Google reportedly tested

The software 1-800-Dentist uses is called Optimizely. It allows publishers to easily carry out so-called A/B tests—statistical horse races between two or more versions of a website. Optimizely was founded four years ago by Dan Siroker and Pete Koomen, former product managers at Google, a company where A/B testing is used extensively to rate how search results are displayed.

The startup thinks any website, large or small, can be optimized, and its ideas got a boost of publicity from Siroker's close involvement with President Obama's reëlection campaign, which broke records for online fund-raising. Kyle Rush, head of optimization for Optimizely, who ran testing for the Democrats in 2012, says the campaign used A/B testing to weigh every change to its fund-raising Web page, discovering big improvements along the way. At one point late in the race, they found that adding a personal message from the president—"Stand with me, work with me …"—led to an 11.3 percent increase in online donations to the campaign by visitors to the page.

Yet testing also upset the campaign team. Time was tight, and Rush, just a midlevel employee, was running experiments that didn't always work out. "We would do variations and it would drop the conversion rate by 30 percent for three hours," Rush says. "That caused a panic. People said, 'Oh my God, we can't afford any more risks like that!' The campaign environment is very risk averse. And that's the main thing that has to be untaught in most businesses."

At least 15 percent of the top 10,000 websites are conducting A/B tests at any given time, according to BuiltWith, an Australian company that scans sites to see what types of third-party software they are using. The not-for-profit Wikimedia Foundation, which publishes Wikipedia, tested various tweaks to its fund-raising messages throughout 2013, with results a spokesman calls "amazing." The organization says the more effective its appeals are, the fewer of them it has to show.

"No one is really committed to their version anymore, because testing proves over and over again that the smartest people in the room are just wrong."

But there are risks to following the data. It can turn into a tyranny of mob taste that diminishes the judgment of professionals or artists. In 2009, a top Google designer named Douglas Bowman quit, complaining that the company "couldn't decide between two blues, so they're testing 41 shades … to see which one performs better." While Google says the designer's story is not entirely accurate, the professional anxieties are real.

"Now anyone with the data can make the call," says Rush. "And that is very frightening for a lot of organizations."

Traditional media companies, in particular, aren't ready. Often, publishers don't have clear objectives, with editors, designers, and advertising salespeople each advocating different aims. Without a clear goal, says Rush, "software is not going to help you."

Some successful new Web publishers are born with optimization at the center of their decision making. One is Buzzfeed, an eight-year-old news site that is perfecting ways to increase page views using A/B testing and other statistical techniques. Its trademark "listicles" (one typical story: "10 Problems That Only Short Girls Understand") are viewed by 130 million people a month. That's more than four times the number who read the *New York Times*.

In fact, intensive testing appears to be reshaping what the Web looks like. But the page designs that are succeeding won't win any awards for art direction, just as listicles don't win Pulitzers. Even proponents of optimization technology admit it can produce sites with simple, cookie-cutter looks.

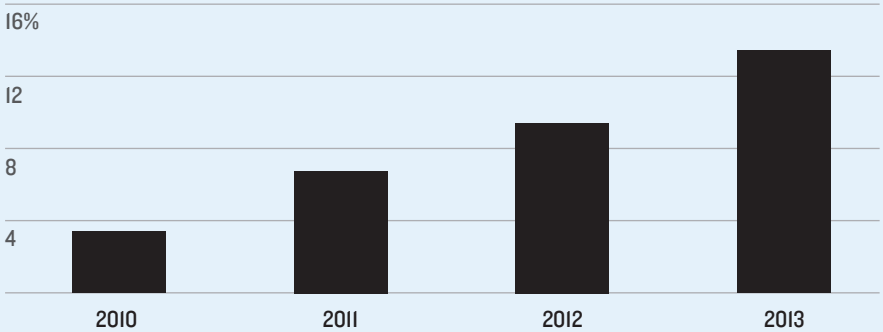
But A/B testing is spreading because it's become easy to do. Optimizely says it can pick a winning design after as few as 100 visits for sites that have never been optimized. In practice, running experiments is often much harder. At 1-800-Dentist, which is based in Los Angeles, Kharkats says he's testing text and images for several slightly different landing pages and estimates that he will need 150,000 visitors to each in order to detect a difference. That could take months, he says.

By now, everyone at 1-800-Dentist is used to the idea that the results could be surprising. One picture that won out showed a short-haired male dentist firmly gripping the shoulder of a female patient. That's not something most dentists would even do. Kharkats himself admits it's a little weird. "We did test different pictures. This guy beat the other versions. Don't ask me how," he says.

—Antonio Regalado

Seeking Perfection, More Websites Run Experiments

Percentage of the top 10,000 websites that use A/B testing technology



SOURCE: BUILTWITH SURVEY OF DETECTABLE THIRD-PARTY SOFTWARE

Leaders

Scientific Thinking in Business

More than technology, businesses need the scientific method.

● Throughout history, innovations in instrumentation—the microscope, the telescope, and the cyclotron—have repeatedly revolutionized science by improving scientists' ability to measure the natural world. Now, with human behavior increasingly reliant on digital platforms like the Web and mobile apps, technology is effectively "instrumenting" the social world as well. The resulting deluge of data has revolutionary implications not only for social science but also for business decision making.

As enthusiasm for "big data" grows, skeptics warn that overreliance on data has pitfalls. Data may be biased and is almost always incomplete. It can lead decision makers to ignore information that is harder to obtain, or make them feel more certain than they should. The risk is that in managing what we have measured, we miss what really matters—as Vietnam-era Secretary of Defense Robert McNamara did in relying too much on his infamous body count, and as bankers did prior to the 2007–2009 financial crisis in relying too much on flawed quantitative models.

Many of the most consequential decisions offer only one opportunity to succeed.

The skeptics are right that uncritical reliance on data alone can be problematic. But so is overreliance on intuition or ideology. For every Robert McNamara, there is a Ron Johnson, the CEO whose disastrous tenure as the head of JC Penney was characterized by his dismissing data and evidence in favor of instincts. For every flawed statistical model, there is a flawed ideology whose inflexibility leads to disastrous results.

So if data is unreliable and so is intuition, what is a responsible decision maker supposed to do? While there is no correct answer to this question—the world is too complicated for any one recipe to apply—I believe that leaders across a wide range of contexts could benefit from a scientific mind-set toward decision making.

A scientific mind-set takes as its inspiration the scientific method, which at its core is a recipe for learning about the world in a systematic, replicable way: start with some general question based on your experience; form a hypothesis that would resolve the puzzle and that also generates a testable prediction; gather data to test your prediction; and finally, evaluate your hypothesis relative to competing hypotheses.

The scientific method is largely responsible for the astonishing increase in our understanding of the natural world over the past few centuries. Yet it has been slow to enter the worlds of politics, business, policy, and marketing, where our prodigious intuition for human behavior can always generate explanations for why people do what they do or how to make them do something different. Because these explanations are so plausible, our natural tendency is to want to act on them without further ado. But if we have learned one thing from science, it is that the most plausible explanation is not necessarily correct. Adopting a scientific approach to decision making requires us to test our hypotheses with data.

While data is essential for scientific decision making, theory, intuition, and imagination remain important as well—to generate hypotheses in the first place, to devise creative tests of the hypotheses that we have, and to interpret the data that we collect. Data and theory, in other words, are the yin and yang of the scientific method—theory frames the right questions, while data answers the questions that have been asked. Emphasizing either at the expense of the other can lead to serious mistakes.

Also important is experimentation, which doesn't mean "trying new things" or "being creative" but quite specifically the use of controlled experiments to tease out causal effects. In business, most of what we observe is correlation—we do X and Y happens—but often what we want to know is whether or not X *caused* Y. How many additional units of your new product did your advertising campaign cause consumers to buy? Will expanded health insurance coverage cause medical costs to increase or decline? Simply observing the outcome of a particular choice does not answer causal questions like these: we need to observe the difference *between* choices.

Replicating the conditions of a controlled experiment is often difficult or impossible in business or policy settings, but increasingly it is being done in "field experiments," where treatments are randomly assigned to different individuals or communities. For example, MIT's Poverty Action Lab has conducted over 400 field experiments to better understand aid delivery, while economists have used such experiments to measure the impact of online advertising.

Although field experiments are not an invention of the Internet era—randomized trials have been the gold standard of medical research for decades—digital technology has made them far easier to implement. Thus, as companies like Facebook, Google, Microsoft, and Amazon increasingly reap performance benefits from data science and experimentation, scientific decision making will become more pervasive.

MIGUEL MONTANER

Nevertheless, there are limits to how scientific decision makers can be. Unlike scientists, who have the luxury of withholding judgment until sufficient evidence has accumulated, policy makers or business leaders generally have to act in a state of partial ignorance. Strategic calls have to be made, policies implemented, reward or blame assigned. No matter how rigorously one tries to base one's decisions on evidence, some guesswork will be required.

Exacerbating this problem is that many of the most consequential decisions offer only one opportunity to succeed. One cannot go to war with half of Iraq and not the other just to see which policy works out better. Likewise, one cannot reorganize the company in several different ways and then choose the best. The result is that we may never know which good plans failed and which bad plans worked.

Even here, though, the scientific method is instructive, not for eliciting answers but rather for highlighting the limits of what can be known. We can't help asking why Apple became so successful, or what caused the last financial crisis, or why "Gangnam Style" was the most viral video of all time. Nor can we stop ourselves from coming up with plausible answers. But in cases where we cannot test our hypothesis many times, the scientific method teaches us not to infer too much from any one outcome. Sometimes the only true answer is that we just do not know.

Some people find this conclusion depressing, but a scientific mind should always remain skeptical of what it knows. Be skeptical of data by all means, but also be skeptical of plausible explanations, conventional wisdom, inspiring ideologies, compelling anecdotes, and most of all your own intuition. The result should be neither total paralysis nor a slavish adherence to data, nor should it in any way exclude creativity or imagination. Rather, it should lead us to a more rational, evidence-based world.

—Duncan Watts is a principal researcher at Microsoft Research and author of Everything Is Obvious: How Common Sense Fails Us.

Emerged Technologies

Software That Augments Human Abilities

How chess and financial fraud led Palantir to human-machine symbiosis.

● The IBM computer Deep Blue's 1997 defeat of world champion Garry Kasparov is one of the most famous events in chess history. But Kasparov himself and some computer scientists believe a more significant result occurred in 2005—and that it should guide how we use technology to make decisions and get work done.

In an unusual online tournament, two U.S. amateurs armed with three PCs snatched a $20,000 prize from a field of supercomputers and grandmasters. The victors' technology and chess skills were plainly inferior. But they had devised a way of working that created a greater combined intelligence—one in which humans provided insight and intuition, and computers brute-force predictions.

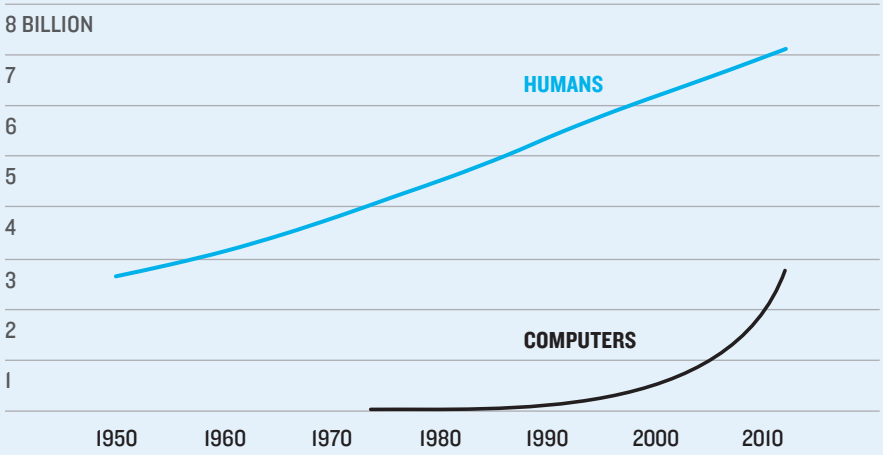
Some companies are now designing software to foster just such man-machine combinations. One that owes its success to this approach is Palantir, a rapidly growing software company in Palo Alto, California, known for its close connections to intelligence agencies. Shyam Sankar, director of forward deployed engineering at the company, says Palantir's founders became devotees while at PayPal, where they designed an automated system to flag fraudulent transactions. "It catches 80 percent of the fraud, the dumb fraud, but it's not clever enough for the most sophisticated criminals," says Sankar.

PayPal ended up creating software to enable humans to hunt for that toughest 20 percent themselves, in the form of a suite of analysis tools that allowed them to act on their own insights about suspicious activity in vast piles of data rather than wait for automated systems to discover it. Palantir, which received funding from the CIA, now sells similar data-analysis software to law enforcement, banks, and other industries.

$450 million
Palantir's estimated annual revenues

Sankar describes Palantir's goal as fostering "human-computer symbiosis," a term adapted from J.C.R. Licklider, a psychologist and computer scientist who published a prescient essay on the topic in 1960. Sankar contrasts that with what

Man over Machine, but for How Long?
World population versus the number of PCs, smartphones, and tablets in use



SOURCE: UNITED NATIONS, ENDERS ANALYSIS, COMPUTER INDUSTRY ALMANAC

he calls the "AI bias" now dominant in the tech industry. "We focus on helping humans investigate hypotheses," says Sankar. That's only possible if analysts have tools that let them creatively examine data from every angle in search of those "aha" moments.

In practice, Palantir's software gives the user tools to explore interconnected data and tries to present the information visually, often as maps that track to how people think. One bank bought the software in order to detect rogue employees stealing or leaking sensitive information. The detective work was guided by when and where employees badged into buildings, and by records of their digital activities on the company's network. "This is contrary to automated decision making, when an algorithm figures everything out based on past data," says Ari Gersher, a Palantir engineer. "That works great. Except when the adversary is changing. And many classes of modern problems do have this adaptive adversary in the mix."

Palantir's devotion to human-computer symbiosis seems to be working. The nine-year-old company now has 1,200 employees and is expanding into new industries such as health care. *Forbes* estimated that it was on course for revenues of $450 million in 2013.

Zachary Lemnios, director of research strategy for IBM, is another Licklider fan. He says that Licklider's ideas helped shape IBM's effort in "cognitive computing," a project that includes virtual assistant software and chips designed to operate like brains. "You will have an entirely different relationship with these machines," says Lemnios. He says it's the most important change to human-computer interaction since the graphical user interface was developed 25 years ago.

Sankar also thinks that Palantir's success shows that large companies are ready to embrace human-computer symbiosis now because of the way people have struck up symbiotic relationships with smartphones in their personal lives. "The consumer experience has recalibrated enterprise at large; they're on the hunt for something that replicates it," he says.

—Tom Simonite

Case Studies

LinkedIn Offers College Choices by the Numbers

To read their futures, young people mine a database of 259 million résumés.

● LinkedIn is widely regarded as a social network for grownups, connecting 259 million people worldwide who put their résumés on display. It was never intended to create a teen haven. While parents may enjoy posting multidecade work histories, it's harder to get high-school-age babysitters and burger flippers excited about documenting part-time jobs.

Enter the data scientists. As early as 2011, LinkedIn began rethinking how it wanted to interact with the under-18 set. Teens might not have much to contribute to LinkedIn's 20-petabyte trove of career information, but they could become some of its most avid data consumers. Specifically, LinkedIn could build a way for them to see where alumni of specific colleges end up working—giving teens a kind of analytics dashboard to lay odds on their futures.

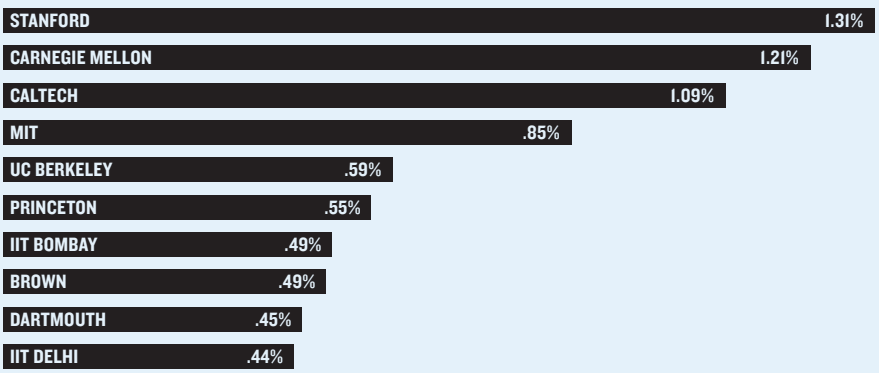
Take well-known U.S. universities such as Carnegie Mellon and Purdue. In each case, LinkedIn has data on the career paths of more than 60,000 graduates. That's a data set big enough to allow for some fascinating fine-grained distinctions. Type in MIT, and you quickly learn that graduates are unusually likely to land jobs at Google, IBM, and Oracle. Plug in Purdue, and employers such as Lilly, Cummins, and Boeing predominate.

Such information is a gold mine for high-school juniors and seniors, says Purvi Modi, a college advisor in Cupertino, California, since most high-school students have only a hazy idea of what careers are out there. By using LinkedIn's tool, students interested in specialties such as solar energy, screenwriting, or making medical devices can pinpoint schools with the best track records of sending graduates into those fields. Modi, who advises about 300 students a year, says about 40 percent of them now cruise through this part of LinkedIn's database, known as University Pages, to get insights. That's impressive, given that the data-combing service has been fully available only since August 2013.

LinkedIn makes money from its huge enrollment in two ways. Recruiters pay as much as $8,500 a year for enhanced access to job candidates, while members can buy various premium services that make it easier to navigate the site. Investors think LinkedIn could be creating a near-monopoly in the global market for talent. As of January, the company was valued at $24.5 billion (a remarkable 728

Hoping to Work at Google?

Schools are ranked by the percentage of graduates employed at Google; based on four million résumés.



SOURCE: LINKEDIN

times annual earnings), reflecting a belief that the social network has just begun to tap the value of its enormous databases.

That high valuation also puts pressure on LinkedIn's team of 68 data scientists to build new tools to extract value from all those petabytes. One set of algorithms now coaches recruiters on "People You May Want to Hire." Other tools alert restless workers to "Jobs You Might Like." The University Pages initiative fits into this pattern; it's a low-key version of "Colleges You Might Want to Attend."

Creating the right tool for college hunters turned out to be surprisingly tricky, says LinkedIn's lead data scientist on the project, Gloria Lau. There wasn't any good way to offer instant lists of good college choices, because teens (along with their parents) generally lack clarity about their priorities at first.

Young people need time to explore on their own, Lau found. By playing with various filters, students who start with broad interests in an area such as engineering can discover subdisciplines and employers that they mightn't have known about at first. One teen might end up being interested in mechanical engineering careers at Tesla or Lockheed Martin, while another might learn that the local college is likely to lead to jobs in petroleum engineering at Halliburton.

This slice-your-own-data approach is slower and more unpredictable than instant recommendations, like those LinkedIn gives to job seekers. From LinkedIn's perspective, that's not all bad. College hunters tend to linger on the site, so they may see more ads or be drawn into greater use of LinkedIn. By letting users shape their own requests, LinkedIn also avoids playing favorites or issuing unflattering reports about specific schools.

So far, LinkedIn isn't charging either student users or campuses for any of University Pages' features. But even a free service can help business objectives. The obvious payoff, says data chief Jim Baer, can be seen in new-member data. LinkedIn's membership is growing by 38 percent a year, with the fastest expansion in the student and recent-graduate segment. *—George Anders*

Emerged Technologies

IBM Expands Plans for Watson AI

IBM invests $1 billion in computer systems that provide "cognitive services" for businesses.

● IBM's computer system Watson vanquished human contestants on the TV quiz show *Jeopardy!* The question now: can it defeat the complexities of the real world?

IBM is counting on it. The company said in January that it plans to greatly expand its efforts to commercialize Watson by putting another 1,500 engineers and marketers to work on the project (out of 434,000 employees), combining it with other "cognitive computing" technologies and investing a further $1 billion.

To IBM, cognitive computing means systems that understand natural (human) language and can draw reasoned conclusions by mining the so-called unstructured data, like text and audio, that accounts for 80 percent of all data businesses confront. In effect, Watson is IBM's first organized foray into commercial artificial intelligence.

A problem facing IBM is that despite big claims, Watson has not always fared as well in real-world circumstances as it did on *Jeopardy!*, where its ability to mine written information and process natural language—or ordinary speech—allowed it to answer trivia questions.

In fact, IBM has generated less than $100 million from selling systems based on Watson, far short of its long-term goal of a $10-billion-a-year business. Some critics say the technology, developed at IBM Research, was commercialized too soon. But Rob High, chief technology officer of Watson Group, as the expanded business unit is now known, says IBM made the right call. "You have to put this stuff into action and refine it. You need examples to work on," he says. "You do hit speed bumps, but I don't think it was premature, it was exactly right."

Under the reorganization, the number of employees working on Watson technologies will increase fourfold, to 2,000. In a sign of its growing importance, the unit will now report directly to IBM's CEO, Virginia Rometty. IBM also plans to combine Watson with other "cognitive" technologies, including voice and image recognition. "It will be a Watson system that can hear, see, and talk," says High.

IBM's commercial goal, says Steve Gold, a senior marketer, is for Watson's style of artificial intelligence to become the engine for "cognitive services" that IBM can sell to businesses. That could include computers able to carry on simple conversations for a call center, he says.

Among IBM's biggest plans for Watson has been to create a system that can read medical records and recommend treatments for cancer patients. Yet so far, the system does not do that very well. Where Watson has struggled is with its vaunted ability to make sense of language on its own. In data presented last year by researchers at the Memorial Sloan-Kettering Cancer Center, which is working with IBM to develop the cancer assistant, Watson correctly identified all the key data in patients' records less than half the time. That's not good enough to inform direct medical decisions.

2,000
IBM employees working on Watson

Cancer turns out to be a hard problem, since unlike crisp game-show questions, doctors' case notes are a maze of jargon and inconsistently used terminology. While Watson is able to recommend the same course of treatment that's suggested by written medical guidelines, it does so consistently only when fed clearly structured data on a patient's case—something that less sophisticated software can do as well. "Watson can easily duplicate a guideline recommendation. But we are

not looking for an electronic version of guidelines," says Mark Kris, a cancer specialist at Sloan-Kettering. "You don't need Watson to do that. We want a machine that doctors can turn to as an advisor and colleague."

Even so, Kris says, IBM is planning to launch a product for cancer centers this spring (IBM declined to comment). That system will make recommendations for treating several cancers based on manually organized inputs—structured data. It will also interpret text notes for lung and breast cancers with reasonable accuracy. While that falls short of the highest hopes for what a system like Watson can do, it may be good enough for a commercial product.

"We do have further to go, but so does this business," says IBM's High. "This [was] the right time to move forward with a bigger investment." —*Antonio Regalado*

Case Studies

Startups Embrace a Way to Fail Fast

How Eric Ries's lean startup method took over Silicon Valley.

● Automated systems routinely make decisions required to trade securities, detect fraud, finger terrorists, and place ads on Web pages. But when it comes to developing these kinds of technology, the hottest decision-making system isn't technological at all. It's a product development philosophy known as the lean startup.

Formulated by a software engineer named Eric Ries, the lean startup method (or "methodology," as its practitioners like to say) is a set of strategies designed to dispel the cloud of uncertainty around innovation. Ries realized that startups needed help in 2001, when he worked for a company that spent $50 million creating an online 3-D world only to learn that no one wanted to hang out in it. But how could any startup be sure it was building the next iPod, and not the next Zune?

Ries's approach, synthesizing ideas from Japanese manufacturing, software development, and the scientific method, has proved to be catnip to Silicon Valley geeks. Ries's 2011 book, *The Lean Startup*, became a best-seller, and awareness for his ideas "approaches 100 percent in entrepreneurial circles," says Tom Eisenmann, who runs the entrepreneurship program at Harvard Business School. "A large fraction of teams think they're following lean startup precepts whether they are or not."

Among Ries's promoters are Jeff Immelt, the CEO of General Electric, a company looking for ways to supercharge development of jet engines, power turbines, and refrigerators. Entrepreneurs from as far away as the United Arab Emirates and Beijing are also embracing the method as a kind of ready-mix formula for emulating Silicon Valley.

In Ries's view, technology risk—the chance that a company can't build what it sets out to build—isn't the problem anymore. Market risk, on the other hand, is a killer. The problem is that businesses often conceptualize, design, and produce a product before they correctly gauge a market reaction. Ries's method deconstructs these sorts of high-risk bets into a plethora of low-stakes gambles that can be tested on real-world customers. The idea is to run a series of experiments as quickly and inexpensively as possible, so that by the time you launch your product, you can be reasonably certain that customers will clamor for it.

An experiment can be as simple as interviewing a handful of potential customers loitering at the local shopping mall, or offering a "minimum viable product" with a tightly constrained feature set—sometimes the mere promise of capabilities that haven't even been built.

While the approach can apply to any new business, the malleability of software lends itself particularly well to fast prototypes and turn-on-a-dime evolution. For instance, entrepreneur Paul Howe subjected his big idea for a Facebook app to the lean method a couple of years ago. His app, BlueSpark, would prompt users to record their purchases, then send a status update telling their friends. Those friends would then download the app, creating a viral sensation. Brilliant, right?

But first, Howe built a simple software script to test his idea on real users. He quickly ascertained that they were horrified. "Facebook used to be about sharing poetry!" one said. Howe dropped the idea. Two competitors, meanwhile, went on to spend millions building their own purchase-alert apps. Nine months later, they threw in the towel, citing hostile reactions. By that time, Howe had already moved on to his next idea.

Ries's method encourages entrepreneurs to "fail fast" and quickly abandon ideas that aren't working. Yet that may mean giving up too soon, skeptics such as investor Marc Andreessen have cautioned. Some of the most important products ever—like the Macintosh computer—came to exist against the odds and gained popularity only through perseverance and brilliant marketing. —*Ted Greenwald*

A Business Theory Catches On

Frequency of Google searches for "lean startup," a popular product development approach.*

*Indexed to peak search volume ("100")

SOURCE: GOOGLE TRENDS

Start with big data. End with an unfair advantage.

Splunk® software collects and analyzes machine-generated big data and transforms it into real-time Operational Intelligence—valuable insight that can make your business more productive and profitable.

Over two-thirds of the Fortune 100™ and more than 300 leading universities use Splunk software and have the business results to prove it.

See how at splunk.com/listen

splunk> listen to your data™

Reviews

Glass, Darkly

For its wearable computer to be accepted, Google must convince people that the device isn't creepy.

By Simson Garfinkel

Google Glass shares much of its electronics and software with the smartphone, but it's a very different machine.

You hold a smartphone in your hand. And we do—at restaurants, at the movies, walking across the street, and even in bed. We use smartphones to check our mail, update Facebook, get driving directions, search the Internet to settle bets, and, sometimes, even to make calls. But Glass you wear on your face, and that fundamentally transforms all these human-computer interactions, making them more intimate. Because you don't use your hands, and because it projects an image onto a transparent screen suspended in front of your eye and uses a vibration to stimulate your inner ear, using Glass is like being naked with the machine: synapses and wires united.

Glass is a head-mounted computer with a camera and a microphone. It sees what you see, hears what you hear. But Glass is not for "life logging"; unlike cameras such as the Narrative Clip, it is not intended to document your day. The battery doesn't have enough juice, and there's no organizing software. Glass is an always-ready smart device that answers your questions, alerts you to messages, and gives you driving directions. The see-through display is just out of your direct line of sight. When you choose to consult the display, it looks like a smartphone screen held eight inches from your face. But when you are doing something else, Glass is easy to ignore. Google's challenge in making the device a successful consumer product will be convincing the people around you to ignore it as well.

Yet for them, Glass is hard to ignore. It's not clear whether that's because it's so new or whether there is something inherently intrusive about this kind of device. When others look at me wearing Glass, the first thing they see is a plastic boom over my right eye with a camera pointed straight at them. Are they being filmed? There's a small translucent prism—the "glass"—with a tiny illuminated rectangle that no one else can read. Am I paying attention to them, or to it? What is it whispering? They can't hear.

Google Glass Explorer Edition (version 2), Software Release XE12

$1,500

When I raise a conventional camera to my eyes and press a button, the people around me assume I'm taking a picture. With Glass, I can take a picture with a wink. If I hold down the button on the touch pad built into the side of the device, Glass starts recording a video and continues until I stop it, or until the device runs out of storage space or its battery dies.

Glass is a marvel of integration and miniaturization, even though the specs don't seem that impressive. The camera records five-megapixel (2528x1856) stills and high-definition (720p) video. It has a dual-core OMAP4430 processor. All that sounds like 2011 technology. But the slower, older processor, combined with the low-power display, lets Glass provide five to eight hours of intermittent use on a smaller battery. The result is that Glass weighs only 42 grams, and since the titanium headband distributes that weight across my cranium, the "nose weight" is similar to that of my ultralight 14-gram rimless eyeglasses.

The processor inside Glass is powerful enough, because most of the processing doesn't happen on your face; it happens in the cloud. Glass reaches the Internet using its internal Wi-Fi radio or by sharing your cell phone's data connection over Bluetooth, a process called "tethering." Sound enters your head via a "bone conduction transducer" that presses just over the ear. Bone conduction offers surprisingly good bass and midrange, but the treble is mushy. Better sound can be had from the included "mono earbud" that plugs into the micro-USB port, or through a pair of stereo buds ($85).

The user interface is based on voice-activated menus and a timeline that's filled with "cards," similar to the Google Now app available for Android and iOS. You navigate the timeline by dragging your finger across the touch pad. Each photo you snap is pinned to the timeline, as are *New York Times* headlines, Google+ status updates, e-mail messages, and notices from other "Glassware" applications. There's also a Web browser, but it's practically useless on such a small screen.

The Glass community

Glass is not ready for general use, and Google knows it. Today's device is too different from existing mobile computers (cell phones, laptops, or car navigation systems), its software too immature, and the whole concept too geeky for it to be a successful mass-market product.

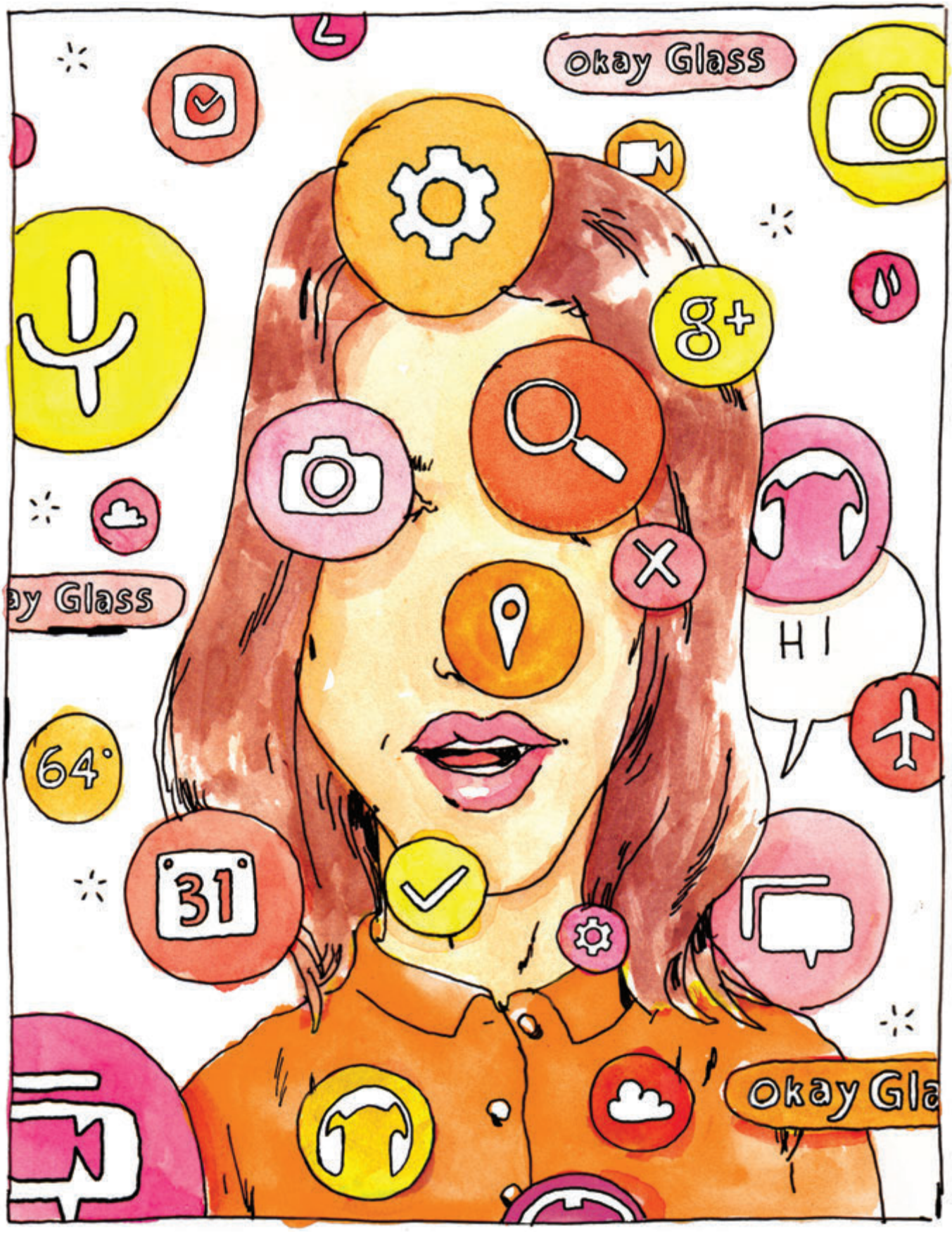


Illustration by Victor Kerlow

Instead, Google spent much of 2013 gradually releasing Glass to increasing numbers of "Glass Explorers," chosen because the company felt sure they would be relentlessly enthusiastic about the technology. The first 2,000 were attendees who signed up at the company's June 2012 developer conference. Next were the winners of a microblogging contest: the people who wrote the 8,000 best tweets and Google+ status updates that contained the hashtag #ifihadglass. They were permitted to pay $1,500 and travel to Google's offices in New York, Los Angeles, or San Francisco to be fitted with the device, a process that included several hours of training. (Some likened the experience of being invited into the Explorer program to finding a golden ticket to Willy Wonka's chocolate factory.) The price, travel, and time commitment ensured that Explorers would be personally invested in working with Google to improve the product. Explorers were paying test subjects, voluntarily turning their homes, workplaces, and friends into Google's living laboratory.

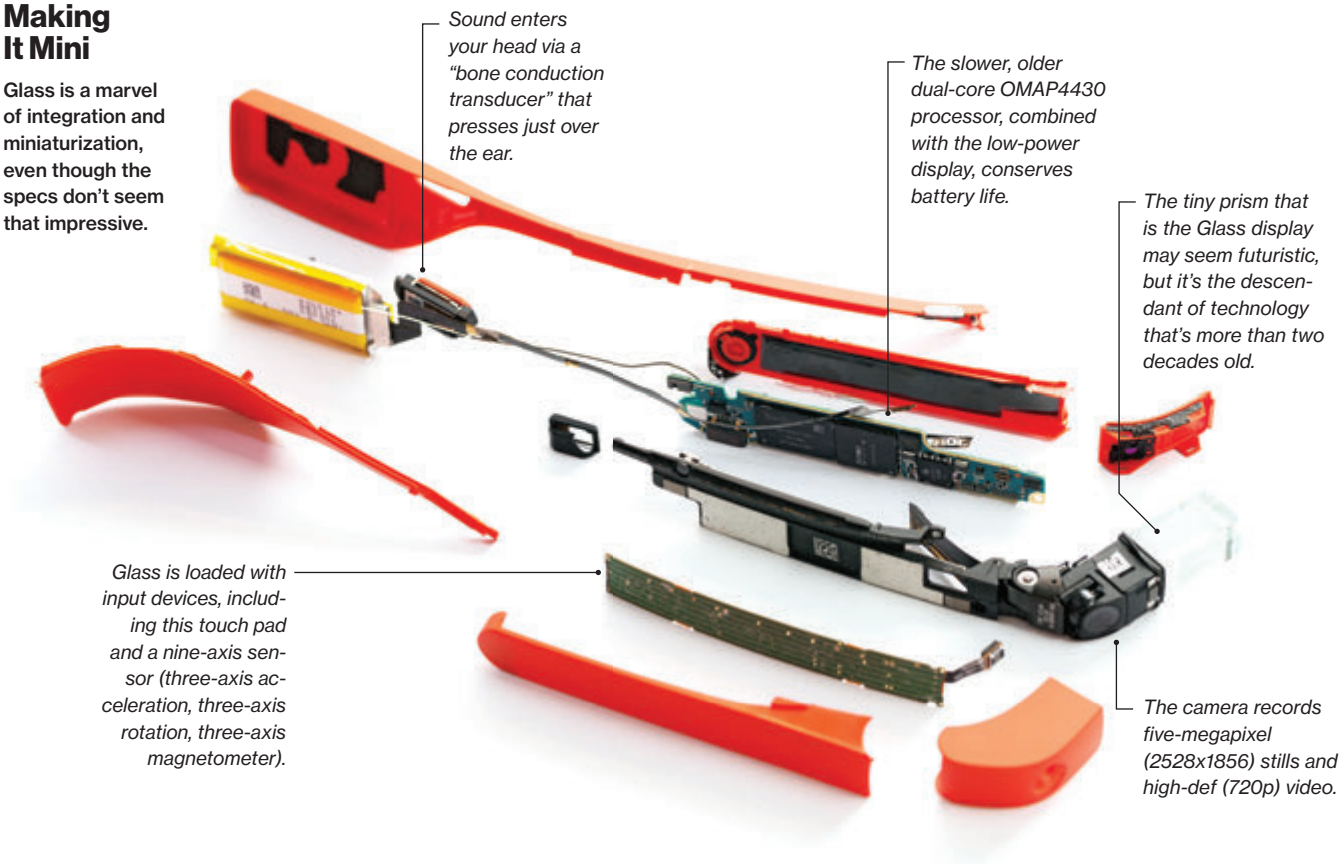
A wave of positive publicity followed. A startup named CrowdOptic gave Glass to some Stanford University cheerleaders, players, and coaches for a few football and basketball games—the video is short and shaky, but it's like hanging with the teams! Several surgeons have used Glass in the operating theater. iJustine, a pretty YouTube personality, uploaded her five-minute review in June; it attracted 1.2 million views within six months. The September 2013 issue of *Vogue* featured Glass in a 12-page photo shoot.

The campaign made wearing Glass seem open, fun, upbeat, hip—even wholesome. Explorers posted smiling selfies and videos: a first-person roller-coaster ride, a walk through a park, or a touching moment with a child (all shot #throughglass). Looking at the images, even those of us who weren't Explorers felt connected. It's a very different feeling from actually standing next to an Explorer; then I feel that I'm being observed, monitored, and analyzed. Or worse, that I'm being ignored.

The Explorers, meanwhile, have become a community. Explorers give advice to newbies and provide troubleshooting advice. Battery life? One

Making It Mini

Glass is a marvel of integration and miniaturization, even though the specs don't seem that impressive.



COURTESY OF SCOTT TORBORG AND STAR SIMPSON

LEAD **YOUR** DIGITAL ENTERPRISE

FORWARD

ARE YOU READY FOR THE NEXT DIGITAL REVOLUTION?

MITSloan
CIO Symposium
Boston Alumni Association
Center for Digital Business

11th ANNUAL MIT SLOAN CIO SYMPOSIUM

Wednesday, May 21, 2014 | Full day event | MIT Kresge Auditorium | Cambridge, MA

The MIT Sloan CIO Symposium combines the academic thought leadership of MIT with the in-the-trenches experience of global CIOs. It is the premier international conference for CIOs and business leaders to look beyond day-to-day issues and explore enterprise innovations in technology and business practices.

PANELS INCLUDE:

- **CEO Keynote Panel**
  Creating the Digital Vision
- **CIO Keynote Panel**
  Leading the Digital Enterprise
- **Academic Panel**
  Are You Ready for the Shifting Frontier of Mind and Machine?*

*The academic panel will highlight a portion of Erik Brynjolfsson and Andrew McAfee's new book, *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*

- Big Data, Analytics, and Insights
- Tracking Business Technology Value in the Digital Enterprise
- Security, Privacy and Availability in the Digital Enterprise
- How Critical is the CIO-CMO Partnership to the Digital Enterprise?
- Will CIOs Still Be Relevant in the Future?
- Transforming 'Digital Silos' to 'Digital HealthCare Enterprise'

Panel topics may change as we continue to refine the program. Check our website for the latest agenda.

To register and for updated information on speakers, sessions, the Innovation Showcase, nominations for the CIO Leadership Award, and sponsorship opportunities, visit:

www.mitcio.com

Explorer developed a free app that tells how much power is left; another started a company that makes PWRglass, a combination lanyard and external battery that nearly triples battery life.

Most of the tech problems are easily solved. But the thornier questions about privacy—or, rather, privacy perceptions—aren't going away. Glass users report being accosted by people who feel sure they are being recorded. The problem: how do you prove you're not taking a picture? (A common suggestion in the forum—to add a little red light—has two obvious problems: it could be hacked so that it would not light up, and it would make Glass seem even more obnoxious when it actually *is* recording.)

Last December, Google opened up the Glass Explorer program to all subscribers to the company's $9.99-a-month music streaming service. The price is still $1,500, but now Google will ship the product directly to anyone. (Well, almost anyone. An employee of the MIT Enterprise Forum, which is managed by *MIT Technology Review*, bought a Glass unit in this fashion and lent it to me. But Google says it is not yet lending Glass to journalists for conventional product reviews, on the grounds that the Explorer edition is not a fully formed consumer product. This review is therefore unauthorized.)

Presumably that high price will still filter out people who might be intimidated by stares. But for Glass to be successful, the broader public has to accept it as well. Otherwise, Glass will remain a tool for specialized users like those surgeons.

Evolutionary, not revolutionary

The first true wearable computer was a foot-controlled machine that the mathematicians Edward Thorp and Claude Shannon invented to help them win at roulette. That computer was built in Shannon's basement lab and then (it's said) tested at a Las Vegas casino in 1961.

Making a Market

How do you de-geekify a smartphone for your face? If you're Google, you attempt to create demand with a strategy built around exclusivity and community.

DO: Give first dibs to the true believers: attendees at your corporate developer conference.

DO: Release it to increasing numbers of "Glass Explorers," each properly vetted for enthusiasm and street cred.

DO: Share it with the people who ignored you as a Stanford undergrad: the coaches and cheerleaders.

DO: Attempt to lure the hipster demographic by designing fashionably chunky frames.

DON'T: Let it fall into the hands of this guy (pictured, author of the review).

Others developed shoe-based computers for counting cards in 1983. These clandestine computers gave their wearers superhuman capabilities, but they needed to remain secret to work as intended.

On-your-face wearables showed up a few years later. These machines were all about cognition: enhancing the wearer's ability to remember, record, and retrieve information. The defining characteristics of machines from this era were their "headgear"—wearable displays that put a video image in front of the user's eye—and one-handed "chording" keyboards that were hard to master. These machines drew stares when people walked around with them, and their users (most of them academic researchers) proudly called themselves "cyborgs." They reveled in their outlandish appearance, between geek and punk.

Back in 2001, wearable-computing pioneer Thad Starner (a Media Lab alumnus, now a professor at Georgia Tech, a consultant to Google, and the intellectual powerhouse behind Glass) wrote about the challenges faced by wearables in *IEEE Micro*. Revisiting those articles 13 years later, one can see that three key problems remain: input, output, and software.

Input: Glass is loaded with input devices, including a camera capable of recording stills and videos, a touch pad, and a nine-axis sensor (three-axis acceleration, three-axis rotation, three-axis magnetometer). But getting *words* into a wearable remains a challenge. Glass does away with the chording keyboard, using speech recognition instead. Google's voice recognition works extremely well for navigating menus, because it's easy to match a second of speech with one of a dozen possible menu choices. The technology is not as reliable for captioning photos and replying to messages, but with practice and patience it can be astonishingly accurate—though you can't mind people overhearing what you are saying.

Output: The tiny prism that is the Glass display may seem futuristic, but it's the descendant of technology that's more than two decades old. Back in the 1990s a company called Reflection Technology developed a similar system called the Private Eye. It was a plastic box the size of a modern cell phone that used fancy optics to put a virtual screen in front of the user's face. These screens were indispensable to the wearable-computer inventors of the 1990s, but because they were big and obscured the eye, they did as much as any-

COURTESY OF GOOGLE; COURTESY OF SIMSON GARFINKEL

thing to make the early users resemble cyborgs. Compared with the Private Eye, today's Glass display is small and fairly unobtrusive. The other output is audio. Today's Glass uses audio to read text, to play music, and for alerts, but not for much else.

Software: As with many pieces of information technology, the biggest challenge for users will not be the hardware but the software. Glass is clearly useful, but its voice-based interface relies on menus that must be spoken in a particular sequence, rather than free-formatted commands that can be issued in any order. For example, if you say "Okay, Glass ... take a picture," the system expects that if you wish to share the image you must next choose how to share it, then select a recipient, then add a caption, all in that precise sequence. Users will want to utter unformatted commands—for example, so you can take three pictures in a row.

Google says that Glass is designed the way it is because eye contact is important to humans. A screen that obstructed the pupil would have a hard time as a product.

Likewise, the system for alerts and notifications is in desperate need of a redesign with a heavy dose of artificial intelligence and user modeling. Instant notifications are an annoyance if you're getting 200 e-mail messages a day. Glass is quite literally in your face. It knows not only where you are but whether you are walking or standing still, whether you are talking to someone, whether that person is talking back, and more. Yet messages from my predefined "Glass Contacts" interrupt no matter what I am doing, while others are silenced even if I'm bored. Knowing when it's the right time to interrupt and when it is not will take more research, and it will probably require algorithms that adapt to each user.

The Glass hardware also has its critics, most notably Steve Mann, who has been developing wearable technology since he was in high school 35 years ago. Mann, a Media Lab cyborg in the 1990s and now a professor at the University of Toronto, says that the Glass display will force each eye to focus at a different distance when images are overlayed on the real world, which could cause eyestrain or dissociation in some people. Mann's headgear employs a different design that projects images into the eyeball with a double-sided mirror and a pinhole projector, supporting a range of "augmented reality" applications like one that automatically labels buildings when you look out at an unfamiliar city.

"It's astounding to me that Google and other companies now seeking to market head-wearable computers with cameras and displays haven't leapfrogged over my best design," Mann wrote last year in *IEEE Spectrum*. (See Mann's "View" on page 10 to read more of his thoughts on wearable computing.)

Google says that Glass is designed the way it is because eye contact is important to humans. (Even Mann's most discreet display prevents eye-to-eye contact.) Google probably made the right call for a mass-market, always-worn display. A Glass camera and screen that obstructed the pupil would have a hard time as a consumer product, at least in this decade.

Glass and the law

In October 2013, Glass Explorer Cecilia Abadie was pulled over for speeding by the California Highway Patrol. When

the officer noticed her Glass—on—she received an additional charge for having a TV screen visible while driving. "Is #GoogleGlass ilegal [sic] while driving or is this cop wrong?" she posted.

Abadie's ticket was thrown out a month later for lack of evidence: the cop didn't see Glass enabled while she was driving, and he couldn't prove the radar gun had been properly calibrated. Nevertheless, California, at least 37 other states, and the District of Columbia all have laws prohibiting the operation of in-car TV screens that can be seen by the driver, says Russ Martin, manager for state relations at AAA, the motorists' association. In case Google Glass falls into some kind of loophole, lawmakers in Illinois, Delaware, New Jersey, and West Virginia have proposed specific bans on using wearable computers with head-mounted displays while driving.

I would not use Glass while driving, but I did use the turn-by-turn directions app while my wife drove us to a party. I'm glad I was in the passenger seat. I spent so much time fiddling with Glass that I would almost certainly have veered off the road, driven through a stop sign, or worse. The issue isn't taking my eyes off the road—it's that Glass steals away my attention. AAA's Martin backs me up, pointing to a growing body of research showing that "hands-free cell-phone use offers no safety benefits over handheld cell-phone use" and that "voice-activated texting or e-mailing is one of the most mentally distracting activities a driver can engage in."

Google's legalese-filled disclaimer that appears when the navigation app starts up seems to be in agreement with AAA but goes even further: "Please keep your eyes on the road and obey applicable laws. Do not manipulate this application while in motion. Directions may be inaccurate, incomplete, dangerous, not suitable, or prohibited. Data is not real-time, and location accuracy cannot be guaranteed. Tap to continue."

Using Glass while driving is probably more dangerous than listening to the radio, but it's probably less dangerous than texting with your iPhone. What's more, Glass might have untold safety benefits—there's an app called DriveSafe that uses the tilt sensor to determine if you are falling asleep at the wheel and directs you to a rest area. Perhaps apps like DriveSafe, combined with an updated navigation app that has a better understanding of human cognition, will one day make the benefits of driving with Glass outweigh the risks.

Even nondrivers are likely to find a growing number of places where they can't use Glass. A hip restaurant in Seattle banned the device, for example. "We want our customers to feel comfortable, not like they're being watched," Jason Lajeunesse, an owner of the Lost Lake Café and Lounge, told *Forbes*. Glass is banned at casinos, of course. Google banned Glass at one of its own press events. And if you are visiting Washington, D.C., you would be well advised to remove your Glass before visiting the White House, the Pentagon (including its Metro station), the House and Senate galleries, or the Supreme Court.

The other kinds of rules Glass users need to understand are Google's—rules enforced by license agreements with Glass app developers, designed to preserve the device's aura of wholesomeness. Google has so far banned the use of facial recognition or voice prints to identify a person or "present personal information identifying anyone other than the user." Google also prohibits use of the camera when the display is turned off, perhaps because taking pictures when the machine is not visibly on might seem sneaky. Last summer, Google banned a sexually explicit app called Tits & Glass. But there is sure to be pressure for adult-themed software.

Developers have skirted Google's rules, of course. A company called FacialNetwork has developed an app called NameTag that looks through Glass, quickly queries a database, and tells you if the person you are looking at is one of 450,000 registered sex offenders (or a near likeness, anyway). Another app, called Sex with Google Glass, will allow to people to see themselves through their partner's eyes, turn out the lights, and even have the computer suggest new ideas. These apps aren't in Google's store, but you can "side load" them by putting Glass in developer mode and transferring them by micro-USB.

But that would be creepy.

"All the world's a stage"

Much of the initial excitement about Glass concerns users' ability to blog with point-of-view photos and video. But as

Making a Myth

An early simulation showed how Glass users would avoid everyday annoyances through an elegantly designed augmented-reality interface (below).

But when the actual user interface turned out to be more prosaic, the activities depicted in promotional videos for Glass became more exciting (above).

COURTESY OF GOOGLE

Glassware improves, we're likely to see a proliferation of new applications that are more useful, like a Word Lens app that's able to instantly translate text between English and five other languages.

For Google itself, Glass is compelling because it makes Google an irrevocable part of the wearer's life. Glass provides Google with hugely personal, sensitive data—just the thing for a company that aims to organize the world's information and gets about 90 percent of its revenue from advertising. I expect the cost of Glass to drop toward $300, because Google will subsidize its use. The platform will be licensed to other manufacturers, just like Android. Already Hyundai has announced that its 2015 Genesis luxury sedan will have a Glass app that will unlock and start the car or help the user find it in a parking lot, among other things.

So far, the biggest problems I've encountered with Glass involve the display. A friend who has no vision problems reported eyestrain and a mild headache after using Glass for half an hour. My left-handed wife reports total frustration from having to use the device with her right eye—apparently her left is the dominant one.

"Glass isn't for everyone," reads the Glass FAQ, adding that people who have had Lasik surgery should consult a doctor first. "Don't let children under 13 use Glass as it could harm developing vision," the FAQ continues, although I suspect that the magic number 13 is more about the Children's Online Privacy Protection Act, which prevents companies from collecting data on youngsters without their parents' consent, and less about a child's developing ocular system. In any event, Google offers those who bought Glass and can't use it a full refund.

Glass clearly has significant opportunities for industrial, scientific, and medical applications. I also think that it could revolutionize the lives of the disabled. Glass can be a head-mounted eye for those with poor vision. It can deliver clear, understandable instructions to those who are cognitively impaired. It can let those who are paralyzed navigate the Web and communicate. Although decades of experience have gone into developing assistive technology for the disabled, it has often been too expensive for the intended users. With Glass they will be able to get the hardware for the price of a few fancy dinners.

Maybe as Glass becomes more useful to more people, it will become commonplace. Future wearables won't generate stares if a lot of people are wearing them.

Maybe as Glass becomes more useful to more people, it will become commonplace. Future wearables won't generate stares if a lot of people are wearing them. But for many, I think, Glass faces an insurmountable problem. It's ugly as sin and impossible to miss. One of my friends, an Android developer and techno-utopian, says he understands the concept—he's even got an Android watch—but he's not interested in Glass. He has perfect vision and doesn't want to wear something on his head. He's waiting for the implanted version.

Simson Garfinkel is a contributing editor to MIT Technology Review *and a professor of computer science at the Naval Postgraduate School. His last article for the magazine was "Windows 8: Design over Usability" (March/April 2013).*

Making Conversation

The charming automated assistant in the movie *Her* isn't realistic. But computerized interlocutors, if they were designed thoughtfully, might make us better people.

By Greg Egan

In the movie *Her*, which was nominated for the Oscar for Best Picture this year, a middle-aged writer named Theodore Twombly installs and rapidly falls in love with an artificially intelligent operating system who christens herself Samantha.

Samantha lies far beyond the faux "artificial intelligence" of Google Now or Siri: she is as unambiguously conscious as any human. The film's director and writer, Spike Jonze, employs this premise for limited and prosaic ends, so the film limps along in an uncanny valley, neither believable as near-future reality nor philosophically daring enough to merit suspension of disbelief. Nonetheless, *Her* raises questions about how humans might relate to computers. Twombly is suffering a painful separation from his wife; can Samantha make him feel better?

***Her* (2013)**
Directed by
Spike Jonze

Samantha's self-awareness does not echo real-world trends for automated assistants, which are heading in a different direction. Making personal assistants chatty, let alone flirtatious, would be a huge waste of resources, and most people would find them as irritating as the infamous Microsoft Clippy. But it doesn't necessarily follow that these qualities would be unwelcome in a different context. When dementia sufferers in nursing homes are invited to bond with robot seal pups and psychiatric conditions are being addressed with automated dialogues and therapy sessions, it can only be a matter of time before someone tries to create an app that helps people overcome ordinary loneliness. Suppose it becomes possible to feel genuinely engaged by repartee with a piece of software. What would that mean for the human participants?

Perhaps this prospect sounds absurd or repugnant. But some people already take comfort from immersion in the lives of fictional characters. And much as I wince when I hear someone say that "my best friend growing up was Elizabeth Bennet," no one would treat it as evidence of psychotic delusion. Over the last two centuries, the mainstream perceptions of novel reading have traversed a full spectrum: once seen as a threat to public morality, it has become a badge of empathy and emotional sophistication. It's rare now to hear claims that fiction is sapping its readers of time, energy, and emotional resources that they ought to be devoting to actual human relationships.

Of course, characters in Jane Austen novels cannot banter with the reader—and it's another question whether it would be a travesty if they could—but what I'm envisaging is not characters from fiction "brought to life," or even characters in a game world who can

R. KIKUO JOHNSON

conduct more realistic dialogue with human players. A software interlocutor—an "SI"—would require some kind of invented back story and an ongoing "life" of its own, but these elements need not have been chosen as part of any great dramatic arc. Gripping as it is to watch a drug baron in a death spiral, or Raskolnikov dragged toward his creator's idea of redemption, the ideal SI would be more like a pen pal living an ordinary life but ready to discuss anything from the mundane to the metaphysical.

There are some obvious pitfalls to be avoided. It would be disastrous if the user really fell for the illusion of personhood, but then, most of us manage to keep the distinction clear in other forms of fiction. An SI that could be used to rehearse pathological fantasies of abusive relationships would be a poisonous thing—but conversely, one that stood its ground against attempts to manipulate or cow it might even do some good. The art of conversation, of listening attentively and weighing each response, is not a universal gift, any more than any other skill. Honing one's conversational skills with a computer—discovering your strengths and weaknesses while enjoying a chat with a character that is no less interesting for failing to exist—might well lead to better conversations with fellow humans.

But perhaps this is an overoptimistic view of where the market lies; self-knowledge might not make the strongest selling point. The dark side that *Her* never really contemplates, despite a brief, desultory feint in its direction, is that one day we might give our hearts to a charming voice in an earpiece, only to be brought crashing down by the truth that we've been emoting into the void.

Greg Egan is a computer programmer and science-fiction author. His story "Zero for Conduct" appears in MIT Technology Review's *SF anthology* Twelve Tomorrows.

Marginally Useful

Bitcoin itself may not flourish as a currency, but the underlying technology is beginning to suggest valuable new applications.

By Paul Ford

Bitcoin, a purely digital currency, is backed by no commodity and governed by no central bank, but it exists because a small number of humans have chosen to believe in its legitimacy.

Its pseudonymous creator (or, more likely, creators) "Satoshi Nakamoto" willed it into existence in 2009, not only describing how the so-called cryptocurrency would work but shipping a full working implementation. The original software had all the hallmarks of a gag or hack: a great, metastasizing practical joke played by clever cyberlibertarian coders upon all who put their faith in fiat (that is, government-backed) currencies.

Then came the believers. Today, there are thousands of people loyal to the ideology and opportunities that Bitcoin represents. They imagine a world where economies are less dependent on banks and governments, and they're actually using Bitcoin, often in disruptive ways. The currency had a rocky start when it became the medium of exchange for illegal drug transactions on Silk Road, but that huge narcotics marketplace was shut down last October and its founder arrested. Indeed, the currency seems more or less respectable. Since Bitcoin is essentially a kind of transaction log, where past transactions are public and known to the world, it is of great interest to prosecutors, who have called the coins "Prosecution Futures." Last year, even U.S. Federal Reserve chairman Ben Bernanke gave them his cautious endorsement.

Bitcoin
bitcoin.org

Bitcoin may or may not become a commonly used currency. As a form of money, it is an established medium of exchange; but so far it is a poor store of value. (See "Bitcoin Economics," page 12.) More than 60 percent of the bitcoins created remain unspent: they are being hoarded speculatively. (No wonder: the value of an individual bitcoin, which was less than a dollar in January 2009, was around $932 in early February.) Those unspent coins could flood the market at any time, depressing their value. Even now, the bitcoin's value fluctuates wildly.

But while it may be wishful thinking to imagine Bitcoin as a true currency, it's a highly functional and effective technology. Bitcoin's "block chain protocol" is built atop well-understood, established cryptographic standards and allows perfect certainty about which transactions occurred when. Nakamoto's original paper is admirably clear. Free and open implementations of software, as we learned from the immense success of the open World Wide Web and Linux, trump everything else.

Money from nothing

What can you do with bitcoins, or with cryptocurrencies in general? You can spend them, of course. You can hold them in a digital "wallet." But whereas fiat currency is minted by a sovereign entity of some sort, you can make new digital money—in fact, it's the only way currency can be created. The process, called "mining" in the Bitcoin vernacular, involves repeatedly running a computationally intensive mathematical function (called a cryptographic hash function) on a set

JON HAN

of randomly seeded inputs until a specific pattern pops up. Many computers all over the world are racing to solve the same function—but typically only one wins. The results are publicized on the Internet for the rest of the Bitcoin network. To create scarcity, the Bitcoin system is designed so that over time the function becomes harder and harder to solve (and therefore requires more computer resources). The number of bitcoins given out as a reward is halved at regular intervals. After 21 million coins have been created, mining stops and no more can be created. For some people, this means *Get in now!*—often using specialized, expensive "mining rigs."

There are other ways to participate in the crypto-economy. Some people have built exchanges, and others have built websites that track the entire transaction history of every coin or fraction of a coin. Still others have built gambling websites like Satoshi Dice, which allow punters to gamble in a weird, automated fashion.

If you already feel jaded about Bitcoin, there are alternatives. Litecoin is a version of Bitcoin that can be mined with regular computers. Dogecoin is a variation on the Litecoin idea that was named after an Internet meme featuring a proud Shiba Inu dog. It is trading vigorously; $30,000 in Dogecoin was raised to send the Jamaican bobsled team to the 2014 winter Olympics. Hundreds of such currencies now exist, such as TeslaCoin or ElephantCoin. They differ in the hashing algorithms they use, the number of coins they make available over time, and other details. Each of them hopes to find a sweet spot in the emerging global cryptocurrency marketplace.

Most interestingly, cryptocurrencies can be used for purposes other than those that conventional currencies fulfill. For example, Namecoin is a system used to create and exchange domain names: the coins contain information about the domain names themselves. Recall that the

domain name market has about $3 billion in revenue per year: it's a good example of a weird, scarce digital resource. And Bitmessage is a Bitcoin-inspired messaging platform that allows for anonymous (or at least pseudonymous) communication. What Namecoin and Bitmessage share is that they allow data to be added to the transaction, making the exchange one not just of perceived value but also of information.

Or take digital art. Larry Smith, a partner at the business architecture consultancy Thematix and an analyst with long experience in digital advertising and digital finance, asks us to "imagine digital items that can't be reproduced." If we attached a coin identifier to a digital image, Smith says, "we could now call that a unique, one-of-a-kind digital entity." Media on the Internet—where unlimited copying and sharing has become a scourge to rights holders—would suddenly be provably unique, permanently identified, and attached to an unambiguous monetary value.

Smith believes that cryptocurrencies will have wide application across business and culture, including both banking and online advertising. For banks, Bitcoin is "just a new source of money," he suggests. "Banks are very hungry to advance their value through technology." It's easy to imagine, say, HSBCoin, or BarclaysBucks, giving investors who want choice in the currencies they use the services of a trusted financial brand.

And what of the enormous revenue-generating engine of online advertising? Advertisers pay to reach highly valued online audiences; they use a variety of technologies, many surprisingly ineffective, to find these individuals. Could cryptocurrencies help? Smith asks us to consider the following scenario: imagine a brand like Dunkin' Donuts that wanted to create a loyalty program. Now imagine that brand creating its own currency: DunkinDollars. Finally, imagine an online advertising campaign where people who clicked on an advertisement would be given the virtual coins. Small amounts of money might be distributed without friction. If large brands could create their own currencies and allow individuals to participate in this marketplace, they could create consumers who were truly invested, in every sense.

The venture capital community has now entered a state of hallucinatory excitement about cryptocurrencies.

The entire web of advertising would suddenly become a more interesting place. Before, the ads seemed to hunt you, but now you would have reason to hunt for ads. The coins you earned could then be exchanged for branded goods, but they could also be exchanged on an open market, like a kind of penny stock. "Pay consumers for clicks and acquisitions," says Smith, defining this new kind of model.

The idea of paying people to look at ads was tried during the last Internet boom (by the startups AllAdvantage—"the dumbest dot.com in the world," according to CNN Money—and the infamous FreePC). And failed virtual currencies such as Beenz and Flooz preceded the success of Bitcoin. But there might be advantages to trying again with the newer cryptocurrencies: offering more value to consumers might make the idea work this time. Right now, the cookie model of Web tracking is dominant; ads are just media objects. But cryptocurrency-mining software, written in JavaScript, has been demonstrated running in a Web browser; you can break up the task of mining and parallelize it. So an advertiser could treat ads as executable software, creating a multimillion-node supercomputer cluster. By engaging with an ad, the user might earn virtual currency while mining and verifying transactions in the network. Perhaps the future of advertising will involve a new set of activities for consumers, as yet unknown.

A post-scarcity economy

Expand banking, make digital art unique, reinvent online advertising—these are just some of the things Bitcoin might do. In response to the perceived opportunities, the venture capital community has entered a state of hallucinatory excitement about cryptocurrencies, with Marc Andreessen, cofounder of Netscape and the venture firm Andreessen Horowitz, performing as the principal cheerleader.

And yet … these applications seem prosaically narrow in comparison to the more perfervid claims of Bitcoin's cyberlibertarian enthusiasts. (According to a video on bitcoin.org, "Bitcoin is changing finance the same way the Web changed publishing"—a claim that would recommend itself only to those who have enjoyed the discomfort of traditional media.) But perhaps that's the point: to succeed, Bitcoin will need to offer real utility to existing markets. The last two decades have suggested a post-scarcity economy, where infinite copies of attractive digital things have a price approaching $0. Maybe that was merely a passing moment that we will look back upon with wonder once limited coins enforce scarcity—once the owner of a piece of digital art can look upon it with satisfaction and know with total, cryptographic certainty that because he paid for it, it belongs to him and no one else.

Paul Ford is a writer who lives in Brooklyn. His review of new authoring tools, "As We May Type," appeared in the November/December 2013 issue.

JOIN US AT THE 3RD

USA SCIENCE & ENGINEERING FESTIVAL

A FREE EVENT

APRIL 23-27, 2014

WALTER E. WASHINGTON CONVENTION CENTER, WASHINGTON, D.C.

DISCOVER SOMETHING NEW

USA SCIENCE & ENGINEERING FESTIVAL

SCHEDULE OF EVENTS:

APRIL 24: X-STEM presented by Northrop Grumman Foundation and MedImmune

APRIL 25: Sneak Peek Friday presented by the Department of Defense

APRIL 23-25: U.S. News STEM Solutions Conference

APRIL 26 -27: GRAND FINALE EXPO

TO FIND OUT MORE: USASCIENCEFESTIVAL.ORG

LINE-UP OF SPEAKERS INCLUDES:

BERNARD HARRIS, M.D.
Physician, NASA Astronaut and Venture Capitalist

ALFREDO QUIÑONES-HINOJOSA, M.D.
Immigrant Worker Turned Neurosurgeon and Researcher

J. CRAIG VENTER, PH.D.
Bored Science Student turned Genomics Pioneer, Biologist, and Entrepreneur

FOUNDING & PRESENTING HOST: LOCKHEED MARTIN

AMERICIUM: Northrop Grumman Foundation, CAT, Chevron Human Energy, Scientific American, Popular Science

NOBELIUM: NewScientist, MedImmune, AAAS, Science Buddies, STEMconnector

BOHRIUM

K&L GATESIUM: K&L GATES

EINSTEINIUM: Radio Disney, NSTA, NIH, DC, The Kavli Foundation, ResMed Foundation, NASA, DOW, ACS, Universal Technical Institute, MIT Technology Review, Francis Goelet, 3M, amazon web services, InfoComm 75, ENGINEERING.com, Planetary, Sigma Xi, American Scientist, Ferrell Family Foundation

KRYPTON: Agilent Technologies, PBS Kids, Forbes/Wolfe, CrazyEngineers.com, The KidWind Project, Physics Today, U.S. News STEM Solutions, Illumina, Inc., Washington FAMILY Magazine, American Architectural Foundation, National Additive Manufacturing Innovation Institute (NAMII), Microsoft, American Farm Bureau Federation, IEEE-USA, WAMU 88.5 - American University Radio, SEGA, DuPont

PLATINUM: Center for Biotechnology Education at Johns Hopkins University, CERVIS Technologies, U.S. Environmental Protection Agency, National Institute of Standards and Technology (NIST), SpaceX, Department of Defense, Northern Virginia Technology Council, Xconomy, Children's National Medical Center, FEI, Purdue University, Genentech, Genetron, Federation of American Societies for Experimental Biology, SCOPE, U.S. Department of State, The Scripps Research Institute, The Science and the Environment, TwoLife Media, Koch Industries, Inc., Georgetown University, ThinkGeek

Demo


1


2


3


4


5

Storing the Sun

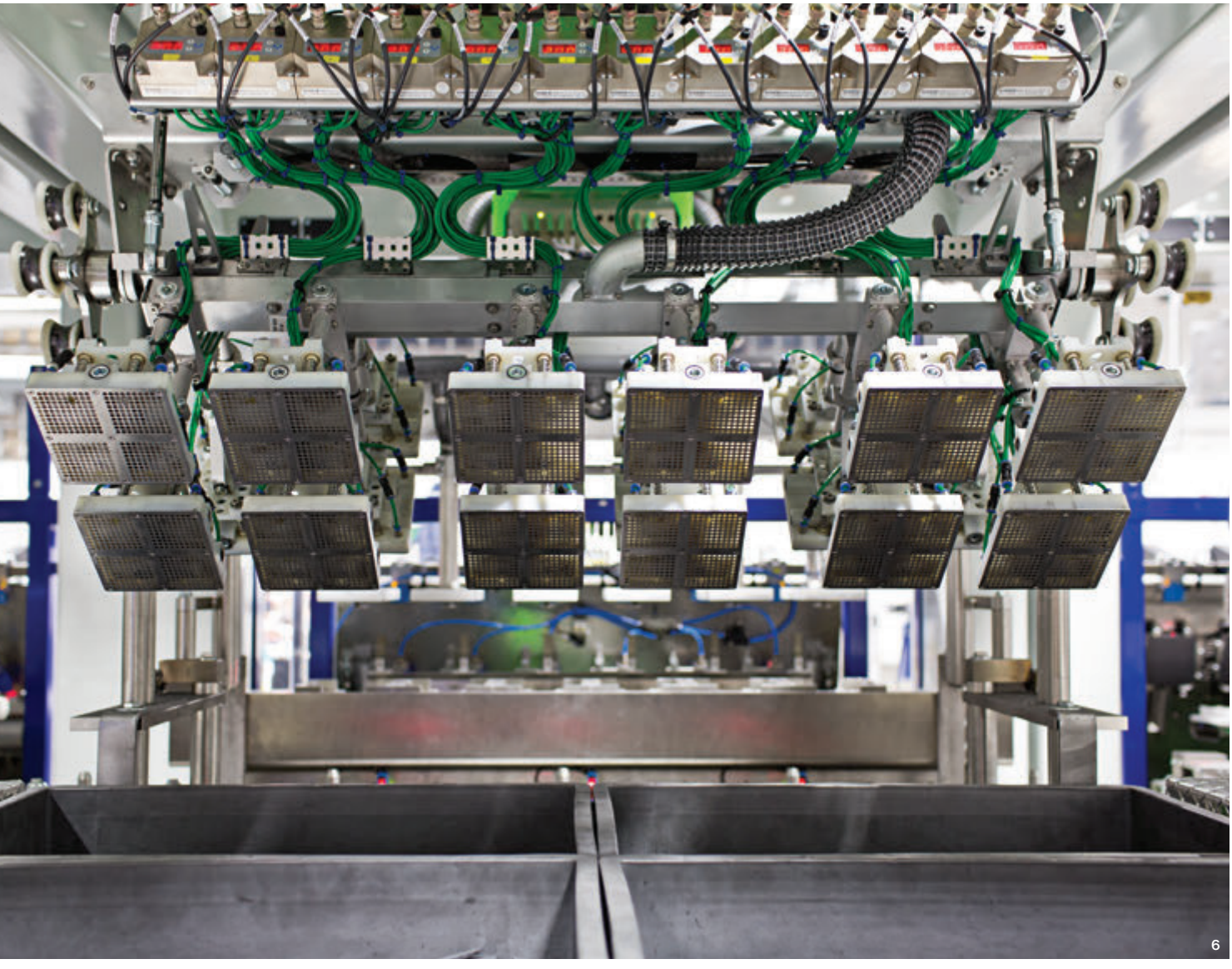
Aquion manufactures cheap, long-lasting batteries for storing renewable energy.

By Kevin Bullis
Photographs by Ken Richardson

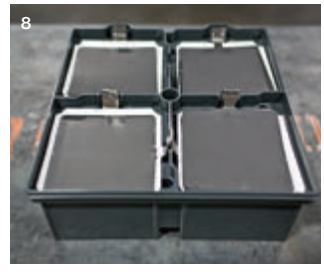
A NEW KIND OF BATTERY INVENTED BY JAY WHITACRE, A professor of materials science at Carnegie Mellon University and founder of the startup Aquion Energy, could make renewable electricity more practical and economical around the world. Aquion is about to start full-scale production of the batteries at a new factory in Mount Pleasant, Pennsylvania.

Whitacre says his batteries' most promising near-term application lies in storing energy from solar panels or other renewable sources in off-grid homes or rural areas, providing a much cheaper 24-hour power source than a common alternative: diesel power. Lead-acid batteries are used for this purpose today, but they are toxic and require air-conditioning to avoid deterioration in some climates, raising costs.

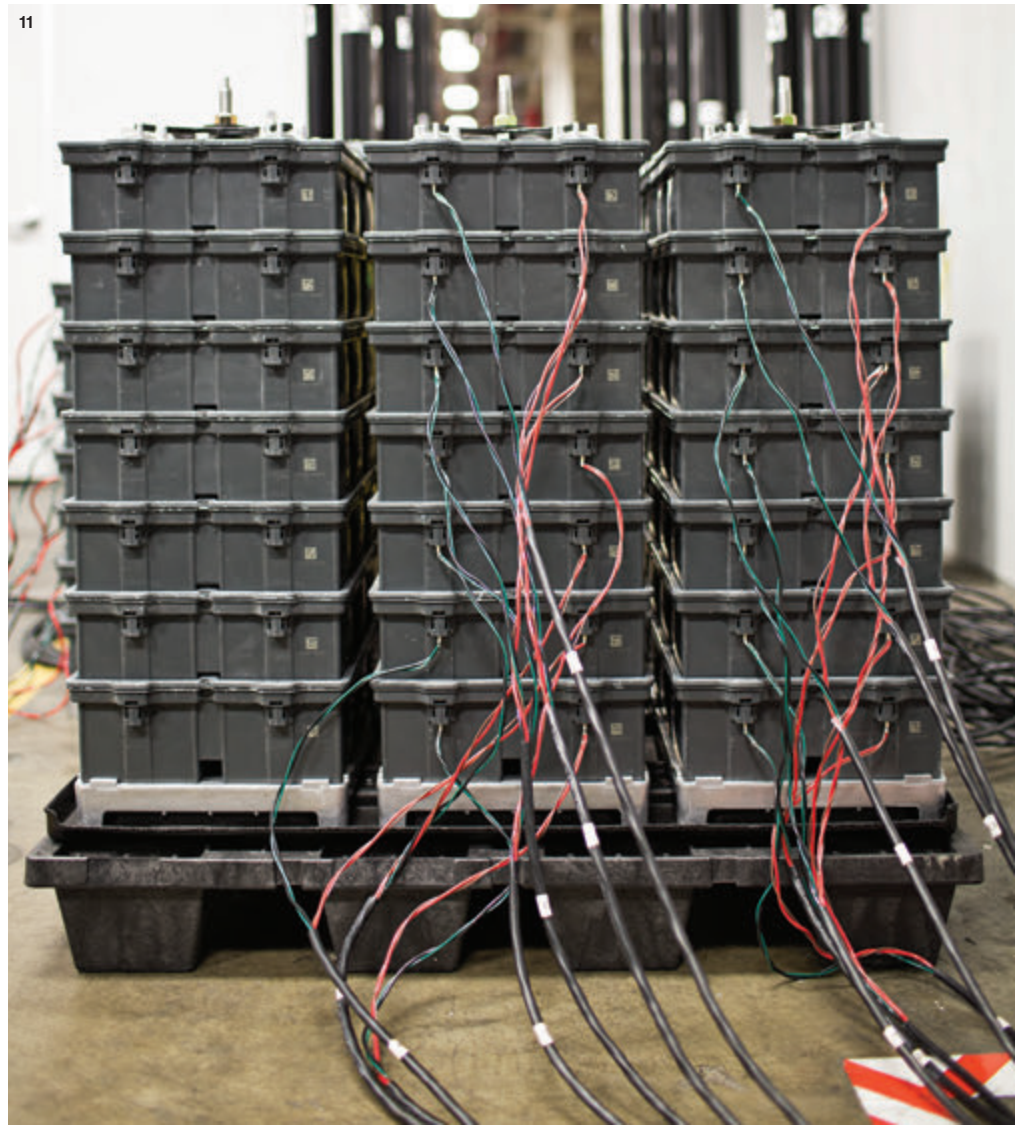
Whitacre's batteries are expected to last twice as long as lead-acid batteries and cost about the same to make. They won't require air-conditioning and will use nontoxic materials. Electrical current in the battery is generated as sodium



1 Jay Whitacre stands in front of a calciner, which bakes electrode powders made of materials such as manganese oxide.
2 Finished electrode powders emerge from the calciner.
3 The granulated electrode material is pressed into wafers.
4–5 The wafers move along an assembly line and are arranged by robot arms for easy stacking.
6 A machine picks up the wafers (each square section picks up four, using suction) and places them in plastic cases.
7–8 The machine fills this empty case, alternating positive and negative electrodes with gray foil current collectors and white membranes that prevent short circuits.
9 After a lid is put on, a worker, Roxanne Van Orsdale, cleans the battery.



10 Seven batteries are stacked and bolted together.
11 The stacks are arranged on pallets and connected to electrical leads for testing.



ions from a saltwater electrolyte shuttle between manganese oxide–based positive electrodes and carbon-based negative ones.

One place the battery could make a big difference: in poor regions of the world that lack an existing electric grid. By 2030, one billion people are expected to get electricity for the first time. That will mean a lot more use of fossil fuels unless renewable power options are as cheap, safe, and reliable as possible. If "even a fraction of that billion can use solar because of our batteries," Whitacre says, the company will be able to reduce not only carbon dioxide emissions but also local pollution from diesel generators.

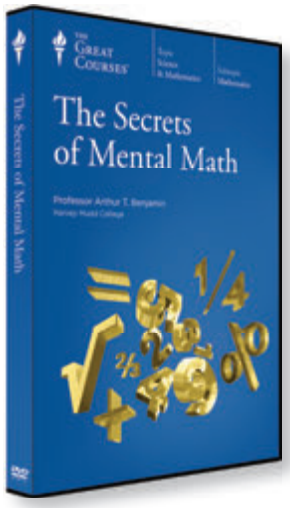
To match the cost of lead-acid batteries, which are among the cheapest types, Whitacre uses inexpensive manufacturing equipment repurposed from the food and pharmaceutical industries. Hydraulic presses originally designed to make aspirin pills stamp out wafers of positive and negative electrode materials, and robot arms built to wrap chocolates are used to package electrode wafers with foils that act as current collectors. At the end of the line, the briefcase-sized batteries are stacked and bolted together. A pallet of 84 batteries, about a meter tall, will store 19.2 kilowatt-hours of electricity. Whitacre says you'd need about 60 such pallets to serve a village of 200 people in a poor country. Two pallets would power a U.S. home for a day.

The technology has its limits. It is best suited for slow and steady operation, not rapidly charging and discharging large amounts of power as some utilities require. And while the batteries are cheaper than other kinds, pairing them with solar panels still can't beat the economics of conventional power plants in most areas. That is why Whitacre is focusing initially on regions without an existing electricity grid.

Aquion has already started shipping batteries to customers for evaluation. The company expects to start full-scale production by this spring, making enough batteries each year to store about 200 megawatt-hours of electricity—enough for roughly 150 solar-powered villages. The factory in Pennsylvania could be replicated in other countries. "If our technology proves out, we won't be able to make them fast enough," Whitacre says.

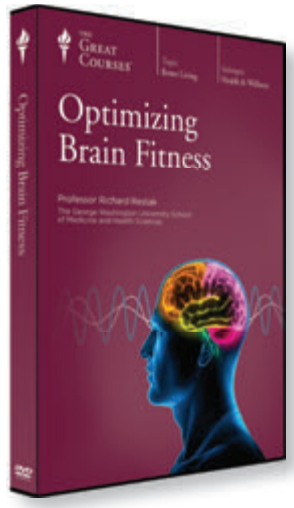
THE GREAT COURSES®

NOW ENJOY BRILLIANT COLLEGE COURSES IN YOUR HOME OR CAR!



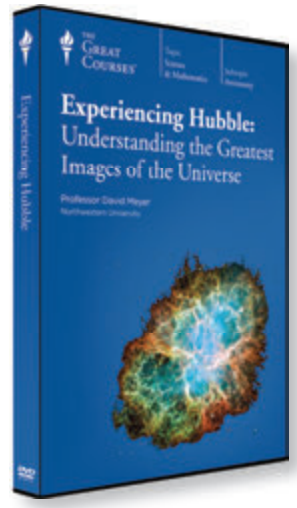
In **The Secrets of Mental Math**, award-winning Professor Arthur T. Benjamin teaches you the basic strategies of mental mathematics. This powerful ability to perform mental calculations will give you an edge in business, at school, at work, or anywhere else that you encounter math.

Course No. 1406
12 Lectures
(30 Minutes/Lecture)
DVD



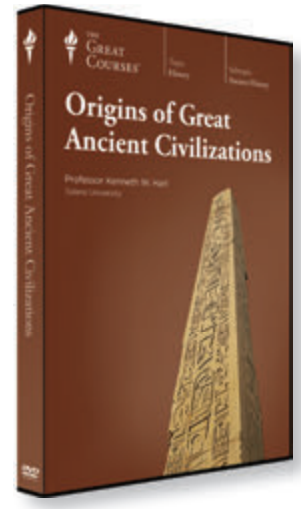
In **Optimizing Brain Fitness**, award-winning Professor of Neurology Richard Restak teaches you how to improve your memory, sharpen your attention, enhance your learning and creativity, and even fine-tune your sensory acuity —all by using one of the most revolutionary discoveries in modern neuroscience.

Course No. 1651
12 Lectures
(30 Minutes/Lecture)
DVD



In **Experiencing Hubble: Understanding the Greatest Images of the Universe**, Professor and Director of the Dearborn Observatory David M. Meyer unlocks the secrets of the universe. In this 12-lecture series, he discusses the most spectacular images ever produced by the Hubble Space telescope.

Course No. 1884
12 Lectures
(30 Minutes/Lecture)
DVD



In **Origins of Great Ancient Civilizations**, Award-winning Professor Kenneth W. Harl gives you a fast-paced and fascinating introduction to the earliest and most influential civilizations of the Near East—including the Sumerians, the Persians, the Mesopotamians, the Egyptians, and more.

Course No. 3174
12 Lectures
(30 Minutes/Lecture)
DVD CD

SPECIAL INTRODUCTORY OFFER!

Over 14,000,000 courses sold since 1990!
THE GREAT COURSES®

Order any one of these BEST-SELLING COURSES for only:

~~$199.95~~ **$9.95 on DVD**
~~$134.95~~ **$9.95 on CD**

+$5 Shipping and Handling
Priority Code: 92315

All orders subject to approval.
Limit of one order per household.
Cannot be combined with any other special offers or promotions.
Offer valid for new customers only.

LIMITED TIME OFFER
SAVE up to **$190**
ORDER BY APRIL 7

ORDER TODAY! Sale Ends Monday, April 7, 2014!

www.THEGREATCOURSES.com/4TECH 1-800-832-2412

29 Years Ago

Slow Motion

A 1985 essay saw hope—and immense challenges—for systems that might allow paralyzed people to walk again.

In the last two decades, researchers have begun to stimulate paralyzed limbs electrically in an effort to restore function to paralyzed muscles. At least 12 research centers worldwide are investigating ways to apply, control, and coordinate such electrical stimulation, which is called functional neuromuscular stimulation. The results so far are promising: these experimental techniques have enabled a small, carefully selected group of paraplegic patients to walk hundreds of meters in the laboratory, using walkers for support.

In all vertebrate animals, motion is accomplished when muscles contract. The muscles are turned on electrically by signals carried by nerves, which form the wiring of the motor-control system. When the spinal cord is injured, motor-control signals from the brain to the muscles may be disconnected.

The hope is to develop 'neural prosthetic' devices that can at least partially replace the function of the injured spinal cord.

The problem, however, is much more difficult than simply restoring signal transmission. Researchers must find some way of approximating the extraordinarily complex system for human motor control.

All existing neural prostheses work in similar ways. First, the patient generates commands either by making a physical movement or by turning a switch off or on. In some experimental systems, quadriplegics move their shoulder a certain way and a transducer mounted on the shoulder translates that movement into an electrical signal.

This signal then prompts muscles in the hand to contract a certain way. If the person pulls his shoulder back, for instance, his finger and thumb open and extend. In this way, a sequence of different shoulder movements can enable a quadriplegic to grasp and pick up a coffee cup.

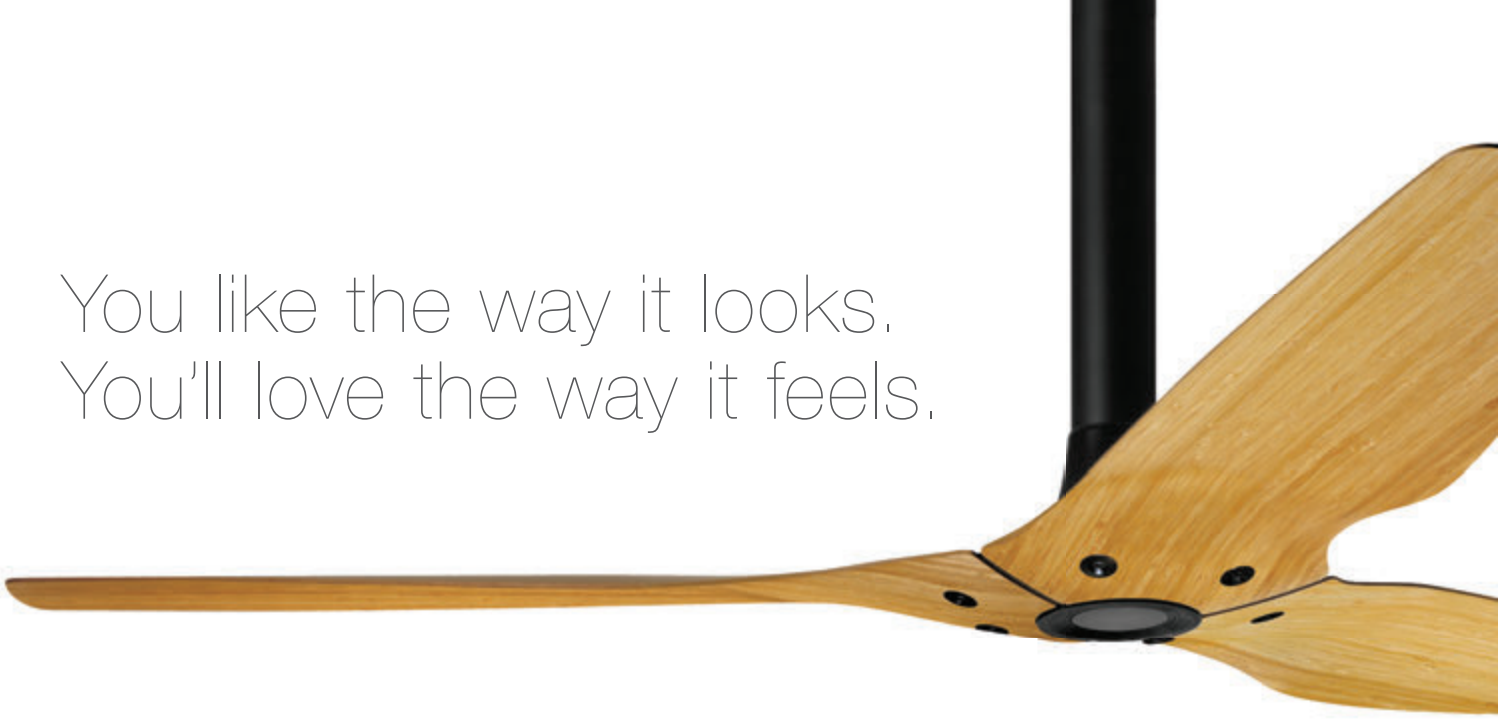
In most experimental systems for paraplegics, the patient generates binary (on-off) signals using simple hand switches. The signals are sent to an electronic 'stimulator,' which uses this information to generate one electrical signal for each electrode. The electrodes carry these signals into the body, where they stimulate specific muscles. When all these muscles are stimulated in the proper sequence, acts such as walking or grasping an object—which so many of us take for granted—can be achieved.

The future of efforts to restore muscle function to disabled individuals through the use of electrical stimulation is promising. However, multidisciplinary teams of scientists, engineers, and health-care professionals will have to work long and hard to solve difficult technical problems before these devices become widely available. This research should not be pressured by premature and exaggerated accounts of success in the popular press, which may raise false hopes among patients and damage the credibility of investigators in the field."

Excerpted from "Helping Paraplegics Walk: Looking Beyond the Media Blitz," by Howard Jay Chizeck, from the July 1985 issue of Technology Review.

MIT Technology Review (ISSN 1099-274X), March/April 2014 Issue, Reg. U.S. Patent Office, is published bimonthly by the Massachusetts Institute of Technology. Entire contents ©2014. The editors seek diverse views, and authors' opinions do not represent the official policies of their institutions or those of MIT. Printed by Brown Printing Company, Waseca, MN. Periodicals postage paid at Boston, MA, and additional mailing offices. Postmaster: send address changes to *MIT Technology Review*, Subscriber Services Dept., PO Box 16327, North Hollywood, CA 91615, or via the Internet at www.technologyreview.com/customerservice. Basic subscription rates: $39 per year within the United States; in all other countries, US$52. Publication Mail Agreement Number 40621028. Send undeliverable Canadian copies to PO Box 1051 Fort Erie, ON L2A 6C7. Printed in U.S.A.
Audited by the Alliance for Audited Media

You like the way it looks. You'll love the way it feels.



The award-winning design, quality craftsmanship and unprecedented performance of a Big Ass Fan® are always in style.

Hidden behind a seamless fit and finish, Haiku's revolutionary motor features Whoosh®, a proprietary algorithm that simulates a natural breeze to keep you feeling up to 40% cooler*. This Big Ass Fan is recognized by *Popular Science* as the world's quietest ceiling fan and rated by ENERGY STAR® as the world's most energy efficient. With 16 unique brightness settings and a digital dimmer, Haiku's patent-pending LED module delivers 80% greater efficiency than traditional bulbs over a lifespan of 50,000 hours.

Visit **haikufan.com/OFFER** and use **promo code MIT314** to receive a free Haiku® info kit.

HAIKUFAN.COM/OFFER 855-651-3009

BIG ASS FANS
No Equal

*Human thermal sensation to air movement frequency, Yizai Xia, Rongyi Zhao and Weiquan Xu (2000)

TECHNOLOGICALLY ADVANCED

SCULPTURE.

FIRST EVER

2014 ELR COUPE

Regen On Demand™

Cut-and-sewn leather-appointed interior

Customized charge settings

cadillac.com/ELR